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BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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CARBONIFEROUS AND PERMIAN CTENOSTOMATOUS BRYOZOA

BY G. E. CONDRA AND M. K. ELIAS

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ABSTRACT

The known Ctenostomatous Bryozoa and similar, but not necessarily related, adnate and penetrating forms in Carboniferous and Permian marine shells of America are described and discussed. Only the genera *Ascodictyon*, *Vinella*, and *Allonema*, and most species of *Rhopalonaria* and *Heteronema* are thought to be true ctenostomes. The principles on which distinction between *Ascodictyon* and *Vinella* is based are revised and redefined. Affinity of *Bascomella*, a supposed ctenostome, is considered doubtful, while *Ptychocladia* is found to be not a bryozoan but a Foraminifera and is described in a separate paper. The first American representative of the rare European genus *Caulostrepsis*, a pseudoboring possibly produced by a worm, is described and discussed. Five new species of ctenostomes and seven new species of doubtful affinity are described.

INTRODUCTION

Many zoologists and paleontologists have contributed to the description and classification of ctenostomatous Bryozoa. First, living forms were studied, and progress was made in establishing their systematic position. Then, fossil forms were found and compared with the living species, and finally a general knowledge was gained of the paleontologic and biologic history of the order.

Our study is based primarily on the comparatively extensive collections of the Nebraska Geological Survey. We review the relations of the fossil genera of Ctenostomata, record the occurrence and description of the old and new species found in the Carboniferous and Permian rocks, and remove *Ptychocladia agellus* Ulrich and Bassler from the Ctenostomata and place it with Foraminifera.

Unfortunately the late Paleozoic Ctenostomata are not well fossilized, primarily because their zoaria contained relatively soft skeletal parts, usually not very calcareous. As a rule, only the molds and ingrowth imprints or replicas of the original structure and form of these fossils are preserved; consequently their taxonomic classification is more or less conjectural. The main zoarial features on which the classification of the living forms is based are not preserved in this kind of fossilization.

Most fossil Ctenostomata are small, not abundant, and usually are overlooked in field collecting and general laboratory study. They occur principally on pelecypods, brachiopods, and crinoid joints, and, more rarely, on rock media, and their detection requires patience and close observation preferably through a low-power lens.

Although the fossil Ctenostomata have not invited the attention of many paleontologists, they do offer a challenge to further collection and study. A close search for these fossils at favorable collecting areas, and in the current collections of crinoids, brachiopods, and pelecypods should add new forms and extend the geographic and stratigraphic range of the known species.

ACKNOWLEDGMENTS

Through the courtesy of various persons we have been privileged to study the fossil Ctenostomata in the collections of the U. S. National Museum and other museums. Helpful guidance in the study has been received from Dr. R. S. Bassler of the U. S. National Museum. We consulted the following colleagues on various matters pertaining to description and interpretation of some of the described fossils: Dr. C. O. Dunbar, Director of Peabody Museum, Yale University; Dr. Paul Galtsoff of the U. S. Bureau of Fisheries; Dr. Winifred Goldring, State Paleontologist of New York; and Dr. N. D. Newell, Professor at the University of Wisconsin. References to the

particular assistance which they rendered are given in the text. All photographs are by M. K. Elias unless otherwise indicated.

The investigation was supported in part by a grant from the Penrose Bequest of The Geological Society of America for which our appreciation is acknowledged.

HISTORICAL REVIEW

Busk, a British biologist (1852), differentiated the suborder Ctenostomata from other recent marine Bryozoa in the British Museum, and Gregory (1893) raised it to the rank of an order. However, Nicholson and Etheridge (1877) were first to recognize certain Paleozoic Bryozoa now classed with the Ctenostomata and described them as three new species of a new fossil genus, *Ascodictyon*.

A number of British scientists expressed conflicting opinions on these fossils as they were compared with Foraminifera, Bryozoa (Polyzoa), and Hydrozoa. Since that time the living Bryozoa were studied in considerable detail by Busk, Brady, Nitsche, Hincks, Joliet, and others, while the study of the fossil Bryozoa including ctenostomes was carried particularly by D'Orbigny, Nicholson, Robert Etheridge, Sr. and Jr., Dollfus, and others. Closer comparison of some fossils with the living ctenostomes was attempted, and the names of certain living genera were applied to fossil species, for instance by Dollfus (1877, p. 96), when he described a Devonian species from France under the name *Terebripora capillaris;* however, Ulrich and Bassler (1904, p. 271) refer it to the fossil genus *Rhopalonaria* of ctenostomes.

In the United States, E. O. Ulrich, John M. Nickles, and R. S. Bassler have led in the investigation and description of the Paleozoic Ctenostomata. The reports by Ferdinand Canu and R. S. Bassler on the North American early Tertiary (1920, Ctenostomata, p. 841–842) and the North American late Tertiary and Quaternary (1923, Ctenostomata, p. 15–16) are the outstanding publications on the Bryozoa of late geological age.

Among the latest contributions is a comprehensive investigation on physiology, anatomy, and taxonomy of the living ctenostomes published in 1941 by Ernesto Marcus. This publication has an extensive list of references on living Bryozoa.

The leading contributions to the description and classification of the Paleozoic Ctenostomata are summarized in the order of their publication as follows:

(1877) Nicholson and Etheridge, Jr. (p. 463) name the genus *Ascodictyon*
(1879) Ulrich (p. 26) names the genus *Rhopalonaria*
(1881) Vine (p. 613–619) describes the Silurian species of *Ascodictyon*
(1887) Vine (p. 179) refers species of *Ascodictyon* to the Stomatoporiidae, which are Cyclostomata
(1890a) Ulrich (p. 173) names the genus *Vinella*
(1890b) Ulrich (p. 367) assigns *Ascodictya* and *Rhopalonaria* to the family Ascodictyonidae of the Ctenostomata
(1891) Whiteaves (p. 212) describes *Stomatopora moniliformis* from the Devonian of Canada. Ulrich and Bassler (1904, p. 282) class this under *Allonema*
(1892) Vine (p. 74–89) refers the Ascodictyonidae to the Ctenostomata
(1893) Ulrich (Minn. Geol. Nat. Hist. Survey, p. 112–115) questions the validity of including *Ascodictya, Vinella,* and *Rhopalonaria* in a single family, Ascodictyonidae, and states that *Rhopalonaria* may represent a family
(1897) Simpson (p. 603, 604) recognizes and lists the genera and species of Ctenostomata

(1900) Nickles and Bassler (p. 19–20) follow Ulrich's (1893) suggestion and recognize the family Rhopalonariidae

(1904) Ulrich and Bassler (p. 258–294) discuss the Ctenostomata, describe several new species, and name the genera *Allonema*, *Hereronema*, and *Ptychocladia*, the last with doubtful biologic relations. They group the genera and families of the Ctenostomata provisionally as follows:

Order *Ctenostomata Busk*
- Family *Rhopalonariidae* Nickles and Bassler
  - Genus *Rhopalonaria* Ulrich
- Family *Vinellidae* Ulrich
  - Genus *Vinella* Ulrich
  - Genus *Heteronema* Ulrich and Bassler
  - Genus *Allonema* Ulrich and Bassler
- Family *Ascodictyonidae* Ulrich (restricted)
  - Genus *Ascodictyon* Nicholson and Etheridge, Jr.
- Position doubtful:
  - Genus *Ptychocladia* Ulrich and Bassler

(1913) Bassler *in* Zittel, *Textbood of Paleontology* (p. 317–318) lists the genera and some species of Paleozoic *Ctenostomata*

(1922) Morningstar (p. 156) names the genus *Bascomella* and describes *B. gigantea* as the genotype.

(1929) Bassler (p. 39–40) gives a diagnosis of the genus *Rhopalonaria* and describes *R. permiana* and *R. timorensis*

(1935) Twenhofel and Shrock (p. 231–233) discuss the Ctenostomata

MORPHOLOGY OF FOSSIL CTENOSTOMATA

GENERAL STATEMENT

The morphology and biological relations of these fossils as interpreted by Ulrich and Bassler (1904) are now accepted generally.

The fundamental parts of the fossil Ctenostomata are the creeping to penetrating stolons and the vesicles attached to them. The stolons are divided into nodes and segments or internodes, and the nodes are expressed as constrictions or are indicated by the branching of stolons, by the attachment of clusters of vesicles, or by the development of a circular cell from which several stolons radiate. The stolons may be creeping, entirely above the supporting medium, or they may be partially or completely immersed (by replacement) in the medium in which the original Bryozoa were able to penetrate. However, when immersed in the medium they contact its outer surface in some points.

The stolons are simple tubes with a thin seldom-preserved wall; when preserved, the walls appear more or less clearly perforated with foramina arranged in a single row or in several parallel rows covering the whole upper surface. The tubes (stolons) are quite comparable in shape, size, and perforation to those of the living Ctenostomata (Pl. 1, figs. 3–5).

EXPLANATION OF TERMS

The following terms are defined to assist the reader in the understanding of their meaning as employed in this report.

COMMUNICATION PLATE: a diaphragm, pierced by one or more minute orifices, occurring between the internodes and at the base of the zooecia. (Adapted from Hincks, 1880)

COMMUNICATION SCARS: marks on stolons and segments to which presumably zooecia or homologous structures were attached

CONSTRICTION: more or less abrupt short narrowing of stolons

FORAMINA: (*see* pores)

INTERNODES: units or links into which the stoloniferous system is divided and which are presumed to be homologous to zooecia

NECK: short, narrow connection between parts of the stoloniferous system

NODE: junction of two successive internodes

OOECIUM OR OVICELL: special receptacle, in which the ova complete their development into the larva (Hincks, 1880)

PORES OR FORAMINA: minute perforations in the wall of stolons, vesicles and other structures, not to be confused with communication scars

SEGMENTS: parts of a stolon differentiated by the development of constrictions or by localized swelling

STOLON (or thread): the creeping tubular stem, by which the individual zooecia or celluliferous shoots composing a colony are held together (Hincks, 1880)

STOLONIFEROUS SYSTEM: composite structure formed by stolons, adnate or embedded in the substance of attachment

VESICLES: apertureless, baglike structures, presumably immature ovicells at various stages of development

ZOARIUM: composite structure formed by repeated gemmation (Hincks, 1880)

ZOOECIUM: chamber in which the polypide is lodged (Hincks, 1880)

LIFE RELATIONSHIP AND GROWTH FORM

In the earliest descriptions, the adnate to partially embedded fossil Ctenostomata were referred to as parasitic (Ulrich, 1890, p. 294; Bassler *in* Zittel, 1913, p. 317–318). However, there is no evidence that the life relationship of either the attached or the embedded fossil forms was that of a parasite. Also, the study of the related living Ctenostomata has shown that, except for the true parasitic *Alcyonidium parasiticum*, they are merely attached to the hard parts of worms, crustaceans, and other marine animals (or plants) and live in epizoic, symbiotic, or comensal relationship. In other words, the creeping, living Ctenostomata merely adhere to and usually share the food with the animals to which they become attached. In some instances the adnate surface of the Bryozoa becomes penetrating, as in *Hypophorella*, which is known to excavate passages in the substance of the tubes of certain polychaet worms, or as in *Terebripora*, which excavates the substance of the shells of mollusks. Since the surface of attachment and the various devices of anchoring observed in the various living Bryozoa do not assume the function of nutrition and thus do not develop any organization for this purpose (as found in true parasites), their influence on the metabolic processes of the colony and on its morphology is negligible. The manner in which living Bryozoa attach themselves is generally disregarded in the taxonomic differentiation of the living forms, which is based primarily on the structure of the zooecia.

RELATIONS OF MORPHOLOGY AND TAXONOMY

Agreeing with this attitude by biologists, we conclude that the difference between adnate and embedded stolons of the fossil does not have family or even generic importance. Furthermore, our observations show that the stolons of some species change readily from merely adnate to partially or completely embedded in the shell

to which they are attached, and since there is no evidence that the zoaria to which these stolons belong were parasitic the stolons were probably able under certain conditions to penetrate the medium upon which they grew by the method of replacement, possibly through metabolic development of some acid capable of dissolving the calcareous shells of the animals to which they were originally adnate. (*Compare* with the action of rootlets of some terrestrial plants on calcareous rocks, on the surface of which they etch out their outline.)

Instead of attaching much taxonomic importance to the ability of penetration of the surface of attachment by the stolons we consider of greater importance both morphologically and taxonomically the structure and difference between the stoloniferous system of *Ascodictyon* and *Vinella*, and on this ground we agree with Ulrich and Bassler that they belong to two different genera, though perhaps not in separate families. Also, we believe it correct and taxonomically important to differentiate between the finer, densely spaced pores and the coarser, less densely spaced openings or scars which, on the ground of their location, size, and spacing are interpreted as the marks of attachment of zooecia or ovicells or both.

Nicholson and Etheridge, Jr. (1877, p. 463) describe the minute perforations of "microscopic foramina" which they originally observed and illustrated on the calcareous vesicles of the fossil *Ascodictyon* and "in some cases" on the "hollow filamentous tubes" (now usually called stolons) to which the vesicles are attached. Although they did not record the size of the minute pores or their number per given space, their detailed sketches (Pl. 1, figs. 9, 10 of this paper) permit us to do so. There are about 30 pores in 1 mm. in *A. stellatum*, 22 to 30 in *A. fusiforme*, and 70 to 85 in *A. radians*. In our measurement of the same kind of pores on the vesicles and stolons of the new species *A. nebraskensis*, which is closely related to these English forms, we find from 45 to 80 pores per mm., which shows that the magnitude and spacing of pores in the American and English specimens are about the same.

The bryozoologists who study the living forms do not describe the magnitude of spacing of pores on the stolons, zooecia, and ovicells of the Ctenostomata and other Bryozoa, but in many instances they illustrate these pores greatly magnified, which permits us to take the desirable comparative measurements and counts. As measured and counted on pedicells of *Ascophodaria fruticosa* (Busk, 1886, Pl. IX, figs. 2-6), on internodes of *Aetea truncata* (Hincks, 1880, Pl. 2, fig. 3) and other Ctenostomata, and on the ovicells and zooecia of *Crisia biciliata* (Busk, 1886, Fig. 1c), *Diastopora obelia*, and *D. suborbicularia* (Hincks, 1880, Pl. 6b, figs. 10, 11), the pores vary from about 20 to nearly 100 per 1 mm., which is a slightly wider range than that observed in the measured species of the fossil *Ascodictyon*. The openings illustrated by Ulrich (1890, p. 174; 1895, p. 114–115, Pl. 1, figs. 1–5) on the stolons of the genotype of *Vinella repens*, and referred to in his description as "very small pores arranged uniserially along the center of the upper surface of the threads," show a much wider spacing—only 4 or 5 in 1 mm. (Ulrich's measurement).

The stolons on which the openings occur show an occasional but very clear tendency of regular differentiation by constrictions into fusiform segments, each segment bearing a single scar, usually located somewhat eccentrically, toward the distal end. In this respect the genotype of *Vinella* shows a tendency which is more completely de-

veloped in the numerous species of *Allonema* as illustrated by Ulrich and Bassler (1904, Pl. LXVII, figs. 1–12), where one can observe all gradations from the elongated stolons with slightly developed but more or less regularly spaced constrictions to the complete differentiation into short sausagelike to beadlike links, each having only one opening located toward its distal end. The magnitude of spacing of these beadlike segments and the corresponding openings compares well with that in the genotype of *Vinella*. Thus in *Allonema ? minimum* which Ulrich and Bassler illustrate (1904, Pl. LXVII, fig. 11; our Pl. 6, fig. 11) there are about 6 to 7 segments and openings per 1 mm. About the same spacing of elongated links or segments may be counted on *Allonema botelloides* Ulrich and Bassler (Pl. LXVII, figs. 2, 3; our Pl. 6, figs. 5, 6), and in the species the authors describe and illustrate the presence of both a "large zooecial pore," occasionally developed on each segment or link, and "surface punctures" which "are nearly always preserved" and are shown on the sketch (Pl. LXVII, fig. 4; our Pl. 6, fig. 7) as numerous parallel rows of minute pores. Neither the size nor spacing of these pores was recorded by Ulrich and Bassler, but judging from their sketch and considering the magnification, their number is apparently between 30 to 40 per 1 mm. Thus they are quite comparable to the pores as counted on the living Ctenostomata and the fossil *Ascodictyon*.

The new species, *Vinella ulrichi*, apparently furnishes a good link between *Vinella* and *Allonema*. It is embedded in a *Composita* shell and consists of stolons comparable to *Vinella* except they are not arranged in a starlike group. The stolons readily change laterally from smooth to annulated or beadlike form, and each short segment which is differentiated by the annulations has a distinct scar facing out of the *Composita* shell, apparently representing the point of attachment for a zooecium or other homologous structure. These stolons could be classified as *Heteronema*, but they are nearer to *Vinella* in their regular differentiation into segments and the pronounced development of scars of attachment.

SUMMARY AND CONCLUSIONS

The structures most important in the taxonomic differentiation of *Ascodictyon*, *Vinella*, *Allonema*, and related genera are the creeping stolons attached to hard parts of various marine invertebrates or embedded in the latter but allowing the attachment to them of free zooecia or homologous parts. The spacing of these openings or places of attachment apparently must be sufficient for the development of zooecia or homologous parts side-by-side, in a single row, as frequently observed in the living Ctenostomata and similar Bryozoa, their densest spacing being about 6 to 7 per 1 mm. Besides these openings, which may or may not be developed, there may be the much finer pores or "foramina" arranged in a single or several closely spaced parallel rows. These pores are at least 3 to 4 times as densely spaced as the scars or points of attachment of zooecia or homologous parts and vary in spacing from 20 to 100 per 1 mm.

The stolons are tubes, entirely or in various degree differentiated by swellings or by constrictions or by both. In some species of *Ascodictyon* they occasionally grade laterally into vesicle-like form by increase in diameter. A chain of vesicles may be formed by a succession of such swellings along a single stolon, as in *Ascodictyon fusiforme* Nichols and Etheridge, which is the genotype. In other forms the stolons are

differentiated by the development of regularly spaced constrictions, each segment or division being marked by a single scar of attachment, as in *Vinella repens* and in *V. ulrichi* n. sp. The complete or nearly complete differentiation of the stolons into segments results in sausagelike and beadlike chains classified in the genus *Allonema*.

The foregoing basis of taxonomic classification of the fossil Ctenostomata is independent of the biologic interpretation of the swellings and constrictions of the stolons. It is based, however, on the distinction between the manner of segmentation of the stolons by swellings or by constrictions and on the distinction between the communication scars which are directly related to segmentation—one opening always corresponding to one segment—and the pores which are not dependent on segmentation and are much denser. The ability of the stolons to immerse into the substance to which they are attached and the manner of branching of the stolons and their arrangement in star-shaped groups are not considered of primary importance.

TECHNIQUE

COLLECTION AND PREPARATION

The technique of the collection and preparation of the Ctenostomata and other adnate microfossils differs from that for most other bryozoan fossils and thus deserves special consideration.

Frequently Ctenostomata are found attached (to immersed) on the inner surface of outer ostracum of the large valves of *Myalina* (*see* figures of *Ascodictyon*) and rarely on the inner surfaces of other pelecypods. They occur just as frequently on some brachiopods. The original species of *Vinella* was found on the inner surface of *Strophomena septata*, the original *Bascomella* on the inside of the external cast of *Spirifer boonensis*, and the new species *Vinella ulrichi* on the outer surface of *Composita argentea*. Many collected specimens of *Ascodictyon* are attached on the inner and outer surfaces of *Chonetes granulifer* and a few on the outer surfaces of *Spirifer rockymontanus*, *Juresania nebraskense*, and other brachiopods. Next in abundance are the specimens collected on crinoid stems (incomplete *Ascodictyon* and *Heteronema*) and on the lateral surfaces of lophophyllid corals and other forms. Occasionally they are attached to the surface of other Bryozoa, as *Ascodictyon* on *Meekopora*. No doubt unrecorded Ctenostomata occur in the various collections of the fossil invertebrates now stored in museums and in paleontological and geological laboratories of universities museums. For example, we have found many specimens on pelecypods, brachiopods, corals, crinoids, and other Carboniferous and Lower Permian invertebrates in the collections of the Nebraska Geological Survey. However, we found none on the invertebrates collected by Condra in Russia in 1937, and as far as we know there is no scientific record of the late Paleozoic Ctenostomata from Russia or other European countries, except Great Britain.

The preliminary search for Ctenostomata in the field is made with the help of an ordinary medium power (×8 to ×10) hand lens which permits one to select those shells which seem to contain adnate or embedded microfossils. Final check and examination is done under microscope. Most paleontologists overlook ctenostomes in col-

lecting hence they seldom appear in the records. Also these fossils are rarely identified on shells from well samples.

The preparation of the fossils for measurement, photographing, sketching, and final study is often necessary even for the seemingly well weathered or naturally prepared specimens. Some of the naturally weathered out specimens are still partially covered by matrix, or, occasionally, by secondary encrustation. The safest way to prepare the fossils is by washing and by soft brushing, and by removal of the obscuring matrix by sharp tools, under a low-power binocular. Tool marks and the accumulated calcareous powder are eliminated by application of weak acid.

Particular difficulty is encountered in the study of these fossils when they are more firmly attached to the rock matrix than to the medium upon which they originally grew. In such cases the shell, when exfoliated may appear entirely free from the adnate fossils, and yet the latter may be embedded in the broken-off negative of the shell in the rock. In such cases, as in the specimen of *Ascodictyon northropi* from Kansas City, Missouri, the ctenostome is exposed from the reverse, and the complete removal of the matrix from its obverse is practically impossible. The procedure for finding the feature of the obverse is the same as usually employed for other Paleozoic Bryozoa when the reverse only is exposed. In this condition the immersed zoarium is cut or ground tangentially, so that in the prepared polished surface of thin section the zoarium is cut at different levels to show the gradual change in the internal structure all the way through, from the obverse to the reverse.

When fossils are preserved now as casts, and now as molds, as, for instance, in the case with *Bascomella gigantea*, preparation of squeezes or replicas by use of ordinary molding clay or guttapercha is indispensable. Regularly shaped dents or pits on various fossil marine shells were well known to paleontologists, but it was not realized that they represent casts of *Bascomella*, which was originally described on molds only. (*See* description of *Bascomella*.)

ILLUSTRATIONS AND MEASUREMENTS

Most of the previously described late Paleozoic Ctenostomata have been illustrated by drawings, and most of the features now considered important were not measured and recorded. Consequently, in the absence of the type specimens the only way for comparison of the described forms with our material is by the measurement and comparison of their published sketches. Our measurements on the published sketches are only approximately correct, because some allowance must be made for generalization and inaccuracies in the indicated magnifications which are inevitable in the process of sketching and publication. Therefore, the source and responsibility for the measurements given in the tables are correspondingly indicated.

We find it possible to photograph practically all satisfactorily preserved Ctenostomata and other adnate fossils. While the direct measurement of the details in the specimens is often difficult, the measurements of the same features on the magnified photographs is quick and accurate, when the magnification is precisely known and standardized. All our magnifications are standardized to ×1, ×2, ×10, ×20, and ×40.

SYSTEMATIC DESCRIPTION

INTRODUCTION

We classify the various Carboniferous and Permian species of the Ctenostomata under the generally recognized genera and discuss in some detail their morphologic and taxonomic relationship but do not indicate their assignment to the families previously erected by Ulrich and Bassler. However, their grouping into Ascodictyonidae, Vinellidae, and Rhopalonariidae may be followed with some reservation and we suggest return to the earlier concept of Ascodictyonidae (Ulrich, 1895, p. 112) in which the genus *Vinella* is included. We show that the Silurian form *Ascodictyon radiciforme* is not a typical *Ascodictyon* but presents a combination of rudimentary features found, in fuller development, in *Ascodictyon* and *Vinella*.

We believe that *Heteronema* is not necessarily a primitive zoarium from which the more complicated zoaria of *Rhopalonaria*, *Vinella*, and *Ascodictyon* have been evolved, but an artificial, though quite convenient, grouping of forms which are incompletely developed or imperfectly preserved, or both. Thus the family classification of *Heteronema* becomes quite arbitrary, unless it is placed with *Vinella* and *Ascodictyon* in the family Ascodictyonidae. Under this conception the Carboniferous and Permian Ctenostomata would be grouped under one comprehensive family, or under the two families Ascodictyonidae and Rhopalonariidae, the latter of doubtful affinity.

We now describe, classify, and discuss the systematic relations of six old genera, also 15 old and 12 new species of Carboniferous and Permian age. We refer to Foraminifera *Ptychocladia agellus* Ulrich and Bassler (1904, p. 290) and add description and discussion of the problematic genus *Caulostrepsis* based on the single original species and on a new species of the genus.

Genus *Ascodictyon* Nicholson and Etheridge, Jr., 1887

1877. *Ascodictyon*, NICHOLSON AND ETHERIDGE, JR., Ann. Mag. Nat. Hist., 4th ser., vol. 19, p. 463–468, Pl. XIX.
1881. ——, VINE, Geol. Soc. London, Quart. Jour., vol. 37, p. 618, 619.
1882. ——, VINE, Geol. Soc. London, Quart. Jour., vol. 38, p. 52, 55, text figs. 1–3.
1884. ——, VINE, Ann. Mag. Nat. Hist., 5th ser., vol. 14, p. 78, 87, text figs. 1–3.
1887. ——, VINE, Yorkshire Geol. Polytech. Soc., Pr., n. ser., vol. 9, p. 183–184, pl. 12.
1889. ——, MILLER, *North American Geology and Paleontology*, p. 293.
1890. ——, ULRICH, Ill. State Geol. Survey, vol. 8, p. 367.
1895. ——, SIMPSON, N. Y. State Geol., 14th Ann. Rept. for 1894, p. 603, fig. 220.
1900. ——, NICKLES AND BASSLER, U. S. Geol. Survey, Bull. 173, p. 19, 140.
1904. ——, ULRICH AND BASSLER, Smithson. Misc. Coll., vol. 45, p. 266–267, 285–289.
1906. ——, (part) BASSLER, U. S. Geol. Survey, Bull. 292, p. 12, 13.
1913. ——, BASSLER, *in* ZITTEL *Text book of paleontology*, 2d English ed., vol. 1, p. 318.
1900. *Vinella*, (part) NICKLES AND BASSLER, U. S. Geol. Survey, Bull. 173, p. 19, 440.
1904. ——, (part) ULRICH AND BASSLER, Smithson. Misc. Coll., vol. 45, p. 266, 272–278, pl. LXVIII, figs. 4–7 only.
1904. *Allonema*, (part) ULRICH AND BASSLER, Smithson. Misc. Coll., vol. 45, p. 266, 279–285, pl. 17, fig. 8 only.
1906. ——, (part) BASSLER, U. S. Geol. Survey, Bull. 292, p. 12, 13, pl. IV, figs. 2, 3 only.

GENOTYPE: *A. fusiforme* Nicholson and Etheridge, Jr. (Ulrich's, 1890, subsequent designation).

Nicholson and Etheridge, Jr. (1877) described three original species of *Ascodictyon* but did not designate a type. Ulrich (1890, p. 367) selected *A. fusiforme*, the first species in the order described by Nicholson and Etheridge, Jr. as the genotype, and at later dates Nickles and Bassler (1900, p. 19, 172) and Ulrich and Bassler (1904, p. 285) designate *A. stellatum* as the type. Although we believe

that *A. stellatum* would serve indeed as a better genotype than *A. fusiforme*[1], its selection violates the rules of priority. Furthermore, the classification of *A. fusiforme* as a species of *Allonema* by Ulrich and Bassler (1904, p. 284), if accepted, would make *Allonema* a synonym of *Ascodictyon*. However, because the holotype for *Allonema* is *A. botelloides* Ulrich and Bassler, *Allonema* may and, in our opinion, should be preserved as a valid generic name, providing *A. fusiforme* is not classified as a species of *Allonema*. We explain in our discussion on *Ascodictyon* why *A. fusiforme* and the two other original species of Nicholson and Etheridge, Jr. should be retained in that genus.

DIAGNOSIS: Zoarium represented by stolons and vesicles. Stolons entire, delicate, broadened into one or several successive fusiform vesicles in some species, occasionally arranged in stellar groups usually around a spherical cell, in most cases somewhat broadened at point of attachment or expanded into full size vesicles. Vesicles oriented with narrower ends toward point of attachment, connected by necks to stolons, occurring singly or in various numbers in stellar groups, but occasionally not developed or preserved. Stolons and vesicles perforated with minute pores in single or several parallel rows. Connecting scars on stolons or vesicles not observed.

DISCUSSION: The original diagnosis of this genus is as follows:

"Organism composite, parasitic, adherent on foreign bodies, composed of numerous calcareous cells or vesicles, the walls of which are perforated by a greater or less number of microscopic foramina, but which possess no single large aperture. The cells may be united almost directly by the intervention of short tubular necks; or they may be disposed in clusters connected with one another by hollow filamentous tubes, which usually anastomose, and which in some cases, at any rate, are likewise perforated by microscopic pores." (Nicholson and Etheridge Jr., 1877, p. 463.)

Vine (1881; 1882; 1884; 1887) accepted *Ascodictyon* in its original sense as he described more species of the group. However when Ulrich introduced the genus *Vinella* for certain fossil forms resembling *Ascodictyon* the concept of the latter became a matter of dispute. Ulrich (1885, p. 112–113), in analyzing the differences between *Ascodictyon* and *Vinella*, says that it is

"most difficult to decide the exact limits of the genus *Ascodictyon* Nicholson and Etheridge Jr., and the only plan that now appears feasible is to include all, and only such forms as possess ovate or pyriforme vesicles. As *Vinella*, on the other hand, I would class those forms in which they are absent."

This division is clear and was for some time generally followed by paleontologists but it does not take into account the possibility of encountering fossilized stages of *Ascodictyon* with vesicles not developed or developed and detached or destroyed before or after the death of the organism.

In the extensive discussion of *Ascodictyon* and *Vinella* by Ulrich and Bassler (1904, p. 273–274, 285–286) they are classified in different families. The distinction between *Ascodictyon* and the family *Vinellidae* made by them is based on the presence in the former of

"two permanently and widely distinct structures—bulbous vesicles and extremely delicate connecting stolons. If the simple or segmented threads of the *Vinellidae* are, as we believe, homologous with the vesicles of *Ascodictyon*, then the connecting stolons of the latter are wanting in this family. If, on the other hand, they represent the stolons, then there is nothing to compare with the vesicles" (Ulrich and Bassler, 1904, p. 273).

This distinction seems quite acceptable. Clearly, it contains no mention of the stellar arrangement of stolons or of the character of attachment of the stoloniferous system, which we consider of secondary importance. However, we find that the difference between the genera *Ascodictyon* and *Vinella* should be expressed in modified terms, emphasizing the manner in which their stolons are differentiated. (*See* our diagnosis of the genera *Ascodictyon* and *Vinella*.) Consequently, we apply this latter principle as the most critical in referring species to the genera.

The selection by Ulrich of *A. fusiforme* Nicholson and Etheridge, Jr. for the genotype of *Ascodictyon* was unfortunate because the single known specimen of this species shows the development of only a few of the elements of a stoloniferous system of the genus, whereas this system is better developed in *A. stellatum* Nicholson and Etheridge, Jr. However, the Rules of Zoological Nomenclature preclude any possibility of a subsequent change of the once properly selected type. The return to the

[1] Vine likewise remarks that "unfortunately this [*Ascodictyon fusiforme*] is the type-species of the authors" (Vine 1895, p. 89).

TABLE 1.—*Key to recognition of the species of* Ascodictyon

Species	Tubes (stolons)					Pore Spacing			
	Diam. in mm.	Spherical initial cells (nuclei)		Width in mm.	Length in mm.	On tubes		On vesicles	
		Dia. in mm.	Spacing in mm.			No. of rows	No. in 1 mm.	No. of rows	No. in 1 mm.
A. nebraskensis Condra and Elias Hughes Cr. Shale, Big Blue Series, Bennett, Nebraska, and Palmyra limestone, Wabaunsee gr., Virgil ser., Pawnee County, Nebraska	.02–.025 (to .05 at central connections)	abt. .11	1.6–2.2	.08–.15	.2–.7	1	45–80	1	45–80
A. (?) *oklahomensis* Condra and Elias Nebraska City limestone, Wabaunsee gr., Virgil series, near Foraker, Oklahoma	.03–.04	.07–.08	abt. 1.5	?	?	?	?	?	?
A. northropi Condra and Elias Drum limestone, Missouri ser., Kansas City, Missouri	.02	none?	.4–1	.05–.12	.20–.50	?	?	?	?
A. northropi Condra and Elias Magdalena limestone, Des Moines ser., near Santa Fe, New Mexico	.02–.03	?	.4–.9	.06–.10	.15–.50	?	?	?	?
A. radians Nicholson and Etheridge, Jr. L. Carboniferous, Lancashire, England	.01	(abt. .1)	1.5–2.5	.05–.08	abt. .5	1	?	1	70–85
A. sparsum Ulrich and Bassler Near top of Chester group, Kentucky	?	?	?	.1–.2	.15–.25	?	?	?	?
A. parvulum Ulrich and Bassler Chester group, Kentucky	?	?	less than .5 apart	?	.07–.12	?	?	?	?
A. stellatum Nicholson and Etheridge, Jr. M. Devonian, Canada	.04–.05	(.1)	2.6(?)	.16–.23	.4–.6	1	abt. 30	4–6	abt. 30
A. fusiforme Nicholson and Etheridge, Jr. M. Devonian, Canada	.13	?	?	.3–.6	.6–1.2	?	?	3–9 No traces of linear arrangement	
A. filiciforme Vine, Wenlock Silurian, England	.1–.2	(abt. .1	?	(abt. .2–.3)	(.2–.4)	1	?	?	?
A. siluriense Vine, Wenlock Silurian, England	(abt. .01)	(abt. .1)	1–2.5	.1–.25	(.2–.5)	?	?	?	?
A. radiciforme Vine, Wenlock Silurian, England	(.01–.25)	(abt. .1)	?	abt. .1	(abt. .4–.5)	1–2	?	1–2	?

original genotype presents no difficulty in the application of the generic name *Ascodictyon* to the various known species, if we can follow the original characteristic of the genus and, as suggested in our modification, emphasize as the most critical character of the genus the differentiation of the stolons into elongated vesicles by the widening of their diameter. The recognition of this feature as generically important was clearly indicated by Ulrich (1890, p. 367) in the brief diagnosis of *Ascodictyon*, where he includes "filiform threads with periodic swellings."

The genotype, *A. fusiforme*, shows numerous wholly differentiated perforated fusiform to pyriform vesicles, connected into irregularly curved chains and attached at one point to a nearly destroyed tubelike stolon. However, the stoloniferous system is developed much better and is more complete in *A. stellatum* Nicholson and Etheridge, Jr. (Pl. 1, figs. 11–15), a typical *Ascodictyon*, which supplements additional zooecial features not observed in the genotype. Its stolons are well developed and show clearly the mode of branching and manner of attachment of the vesicles, singly and in stellar groups. The stolons of the stellar group show also the tendency to widen near the point of their common center of attachment, and at least one stolon in the group is differentiated into a full-sized vesicle (Pl. 1, fig. 14).

In *Ascodictyon radians* Nicholson and Etheridge, Jr., all vesicles are uniformly wedge-shaped and arranged in stellar groups attached by their blunt ends to a central sphere. Only one row of pores is developed in each vesicle. Two well-preserved new species, *A. nebraskensis* and *A. northropi*, are in most respects much like the genotype *A. stellatum*, except their vesicles are more elongated and have only one row of pores. The Silurian *A. radiciforme*, which Vine (1884, p. 83, figs. 1–5; our Pl. 5, figs. 1–6) placed in *Ascodictyon* but Ulrich transferred to *Vinella* (1895, p. 112, 113; *see also* Ulrich and Bassler, 1904, p. 276) is most interesting in other respects. There are some features in this form which indicate relationship to the genus *Vinella* as noted by Ulrich. Its stolons occasionally tend to differentiate into long segments, and the wedge-shaped bodies of the stellate groups do not differ much in diameter from the ordinary stolons. However, these wedge-shaped bodies are quite comparable to the more nearly full-sized vesicles of *Ascodictyon radians*. Furthermore, the differentiation of the stolons in *A. radiciforme* results in proportionally much longer segments than those observed in *Vinella* and *Allonema*, and these segments have one row of pores and no communication scars, which are typical of the latter two genera. Thus it appears that *A. radiciforme* combines some rudiments of the characters, which are more fully and typically developed in *Ascodictyon* and *Vinella*, and therefore its classification with one or the other is uncertain. Perhaps *A. radiciforme* is a conservative descendant from the original stock of the early Paleozoic Ctenostomata from which both *Ascodictyon* and *Vinella* originated. Arbitrarily, we classify it as a primitive *Ascodictyon*. We agree in the classification with *Ascodictyon* of: *A. filiforme* Vine (1884, p. 78–80, Figs. 1, 2, 11; our Pl. 10, fig. 3): *A. siluriense*, Vine (1882, p. 52, Figs. 1, 2; Bassler, 1906, p. 14, Pl. 4, Figs. 6–8; our Pl. 5, figs. 16, 17); *A. youngi* Vine (1891, p. 90, Pl. 4, figs. 3–4; our Pl. 5, figs. 21, 22); *A. floreale* Ulrich and Bassler (1904, p. 288, Pl. LXVIII, fig. 13; our Pl. 5, fig. 18), *A. parvulum* Ulrich and Bassler, (1904, p. 288, Pl. LXVIII, fig. 14; our Pl. 5, fig. 19) and *A. sparsum* Ulrich and Bassler (1904, p. 289, Pl. LXVIII, fig. 15; our Pl. 5, fig. 20). Finally we place arbitrarily in *Ascodictyon* the imperfectly preserved forms with steliar arrangement of stolons which were previously classified with *Vinella*. We list them as follows: *Ascodictyon* (?) *radialis* (Ulrich, 1893, p. 113, Fig. 86; Ulrich and Bassler, 1904, p. 274–275, Pl. LXVIII, fig. 4; our Pl. 5, fig. 15); *Ascodictyon* (?) *radiciforme* var. *conferta* (Ulrich) (Ulrich, 1895, p. 113, Fig. 8, c, d; our Pl. 5, figs. 9, 10), and place here provisionally also the *Ascodictyon* (?) *oklahomensis*, new species. It is difficult to place either with *Vinella* or *Ascodictyon* the peculiar "*Vinella* (?) *multiradiata*" Ulrich and Bassler (1904, p. 276, Pl. LXVIII, fig. 8) the biologic affinities of which seem to be uncertain.

Table 1 includes the better known species of *Ascodictyon* arranged in their stratigraphic order and showing the measurements of their elements.

Ascodictyon nebraskensis n. sp.

(Plate 2, figures 1–6; Plate 3, figures 5–7; Plate 4, figures 2–7)

HOLOTYPE: Nebraska Geological Survey No. 401, on the inner side of outer ostracum of a fragment of a *Myalina* shell, from the Hughes Creek shale, Big Blue series, Permian, about 1½ miles southeast of Bennett, Nebraska.

Silurian, England

DESCRIPTION: Several specimens collected from the single horizon and locality indicate considerable variability of the species in the manner of development. Only in a few specimens, one of which is selected as the holotype, do we find the maximum development of all elements known for this (or any other) species of *Ascodictyon* observed.

The zoarium consists of a system of tubular threads or stolons about .02 to .025 mm. in diameter, along which are occasionally developed circular cells with external diameter of about .11 mm. These cells are invariably the centers from which several stolons radiate. At a few centers of radiation the stolons show distinct gradual enlargement toward the center, up to about twice their normal diameter. In this they resemble the radiating vesicles of *A. radians*, but do not thicken as much as the latter and are considered as somewhat enlarged stolons and not vesicles, or a transition between the two. If the homology of both segments and vesicles to normal zooecia is admitted, the occasional existence of transitionary stages of development between these structures is understandable.

In *Ascodictyon nebraskensis* no transitional stage between the above-mentioned slightly enlarged stolons and completely developed attached vesicles was observed. The attached vesicles are variable and somewhat irregular in shape, usually nearly oval or pyriform to elongately oval, with the sharper end toward point of attachment. Many of the vesicles are variously deformed without showing dents or fractures, as if they were somewhat plastic and thus easily deformed at the time of development. When sufficiently preserved all vesicles show a single row of pores along a linear depression which runs from one short end to another on the outer, free side of vesicles. When the pores are not preserved the lineal depression can be still easily detected.

Vesicles are attached at various points along the stolons or threads, one, two, or more being attached at a single point. Ordinarily they come in a radiating cluster of about 3 to 8 vesicles. They vary from .08 mm. to .15 mm. in width and from 2 mm. to .7 mm. in length.

Specimens of less complete development are frequently observed. In some only stolons and clusters of vesicles are observed. In still others stolons alone are developed, and these are referred to *A. nebraskensis* because they have the same general habitat and size as those observed in the holotype. This species shows clearly subperpendicular branching of the stolons. Other specimens of the species show many clusters of vesicles but no connecting stolons. Finally in a few specimens there are clusters of vesicles and a few clusters of radiating stolons, which extend only a short distance from the central cell, and no connecting stolons between these groups are observed.

Because all these specimens were collected from the same horizon and locality, and the elements observed are invariably of the same size and shape, and are occasionally found together and distinctly interconnected, it is possible to conclude that they belong to the same organism. The lack of one or another of these elements on some specimens may indicate incomplete development or, more likely, at least in the majority of cases resulted from imperfect preservation or differential weathering. The fact that clusters of vesicles alone are sometimes preserved with no connecting stolons, seems to indicate that the latter were not preserved, or, more likely, were destroyed by differential weathering; that is if it is correctly understood that vesicles are not developed independently but always develop from the stolons. Field observations on various rocks provide ample evidence of the variability of differential weathering. Fossiliferous rocks may weather under certain conditions with about equal rate of destruction of the fossils and the matrix, but under other conditions the fossils weather faster than the matrix, and weathering causes development of external casts. However, the matrix may weather faster than the fossils, thus liberating the latter. As they weather out in this manner they are preserved in various degree of perfection, depending on the rate of differential weathering of their parts. It is generally true that the most delicate parts of fossils are destroyed at the earliest stages of weathering, but even in this case some variation in the order of destruction of delicate parts is evident.

In *Ascodictyon nebraskensis* the most perishable part in the course of weathering is the thin wall of the vesicles and the stolons. In this wall rows of pores occur, and when the wall is gone all evidence of pores disappears. Out of the several specimens of this form collected from the type locality the walls of the stolons and vesicles are preserved only on one specimen, which is selected as the holotype. In all other specimens, where stolons and vesicles are observed, they are actually the internal molds. Next in the order of destruction are usually the internal molds of the stolons. However, in some specimens no clusters of vesicles are preserved and yet the internal molds of the stolons are well developed. Perhaps in this case it is more likely that the vesicles become detached during the life of the organism or soon after its death and burial and fossilization.

DISCUSSION: This species is nearest to *A. radians* Nicholson and Etheridge, Jr. from the Lower Carboniferous of England, in having only one row of pores on the vesicles and in having the starlike arrangement of the vesicles and tubes; but the shape of vesicles is different from that in *A. radians*. The vesicles of *A. nebraskensis* compare in size, shape, and arrangement with those of *A. stellatum* Nicholson and Etheridge, Jr. from the Middle Devonian of Canada, but in the latter there are several rows of pores in the vesicles.

OCCURRENCE:

(1) Holotype and topotypes on inner side of outer ostracum of *Myalina* (*Orthomyalina*) *slocomi* Sayre. Hughes Creek shale, Big Blue series, Permian. One mile southeast of Bennett, Nebraska.

(2) On inner side of outer ostracum of *Myalina* (*Orthomyalina*) *slocomi*. Wabaunsee group, Pennsylvanian. Seven miles south, 1 mile west of Pawnee City, Nebraska.

(3) On outer side of dorsal valve of *Juresania nebraskense*. Langdon shale, Wabaunsee group, Pennsylvanian. Near Aspinwall Ferry, southeast of Nemaha City, Nebraska.

(4) On outer side of dorsal valve of *Chonetes granulifer*. Hughes Creek shale, Big Blue series, Permian. Three miles south of Stine, Nebraska.

(5) On outer side of *Juresania nebraskense*. Sallyards limestone, Grenola formation, Big Blue Series, Permian. Near Pawnee, Oklahoma.

(6) On *Meekopora prosseri*. Hughes Creek shale, Big Blue series, Permian. One and a half mile west of Glenrock, Nebraska.

Ascodictyon northropi n. sp.

(Plate 3, figures 1–4)

HOLOTYPE: Nebraska Geological Survey No. 413, on *Spirifer opimus* Hall, from Magdalena limestone (of Des Moines age), Lower Pennsylvanian near Santa Fe, New Mexico. This species is named for Professor F. A. Northrop, of the University of New Mexico, who sent us a large collection of Bryozoa in which the genotype specimen was found.

DESCRIPTION: The two specimens of this species collected from two localities are considered conspecific but are in different states of preservation which somewhat complicates their comparative study. The specimen we selected as the holotype (Pl. 3, figs. 1, 2) consists of a large number of small stellar groups of vesicles crowding along some parts of the upper surface of both valves of a nearly completely preserved shell of *Spirifer opimus* Hall. The vesicles are represented by internal molds, the thin outer wall not being preserved. The stellar groups of the molds are covered by a thin calcareous film which extends over the adjacent part of *Spirifer* shell. The partial removal of this film was difficult because the calcareous film does not differ much in hardness from the fossil it encrusts and adheres to tightly. On the photograph of this specimen the remainder of the film is seen as a whitish encrustation partially covering the edges of the vesicles. Because of this it was possible to measure correctly the length and width of the vesicles only in the places where they are better exposed from under the crust, their width varying from .06 to .10 mm. and length from .15 to .50 mm. The transparent crystalline calcite which furnishes the substance of the molds tends to aggregate into a continuous prominent shapeless granular mass in the center of the stellar groups, and it is not clear whether there is anything like the spherical cell in these centers. A faint band or cord can be seen traversing internally the central part of the molds of the vesicles in a straight line from base to apex.

The connecting stolons between the centers of the stellar groups are seldom preserved. Their diameter is about .02 to .03 mm. The distance between the center of the crowding stellar groups varies from .4 to .9 mm. In the second specimen of the species (Pl. 3, figs. 3, 4), the vesicles are filled with granular transparent calcite and are attached in crowded stellar groups to the portions of the inner surface of a valve of *Myalina* (*Orthomyalina*) *slocomi* Sayre. Here the hard calcareous shale of the matrix adheres to the outer surface of *Ascodictyon* vesicles so tightly that when the surface of the *Myalina* shell is cleavaged free from the matrix, the whole system of *Ascodictyon*, which consists of the adnate stolons and the stellar groups of vesicles, remains embedded in the broken off matrix and its base blends with the latter into a continuous smooth surface, which is the negative of the surface of the *Myalina* shell. Thus in this case we are observing not the upper, but the basal surface of *Asco-*

dictyon, which is normally unexposed. This disadvantage of having the obverse concealed by the matrix was in this case more than compensated by the convenience which it offered for preparation of a tangential thin section. The thin section thus prepared (Pl. 3, fig. 3) shows very distinctly the presence of walls in the stolons and vesicles. The thickness of the wall is about .007 mm. The only other data on the wall in *Ascodictyon* seems to be the drawings by Nicholson and Etheridge, Jr. (1877, Pl. 19, figs. 4, 5, 7; our Pl. 1, figs. 14, 15) in which the thickness of the wall is indicated. Our measurements of it on these drawings show about the same thickness for the wall as the figures obtained by us by precise measurements on the slide of *Ascodictyon northropi*.

The principal measurements of the specimen are as follows: diameter of the connecting stolons .02, mm. to .03 mm.; distance between the centers of stellar clusters, when the latter are crowded, from .4 mm. to .9 mm. Vesicles vary from .06 mm. to .10 mm. in width and from .15 mm. to .5 mm. in length.

Besides the predominant ordinary stellar clusters the vesicles occasionally form smaller groups attached at longer intervals along a few stolons.

DISCUSSION: This species is nearest to *A. nebraskensis* from which it differs in closer spacing of the stellar groups of vesicles and their more slender average shape. No pores have been found on either the stolons or vesicles of this species. The stolons are about like those of *A. nebraskensis*.

OCCURRENCE:

(1) On *Spirifer opimus* Hall. Lower part (corresponding to Des Moines series) of Magdalena limestone, Pennsylvanian. Near Santa Fe, New Mexico.

(2) On inner side of outer ostracum of *Myalina* (*Orthomyalina*) *slocomi* Sayre. Middle part of Drum limestone, Missouri series, Pennsylvanian. From near City Water Works, North Kansas City, Missouri.

Ascodictyon (?) *oklahomensis* n. sp.

(Plate 4, figure 1)

HOLOTYPE: Nebraska Geological Survey No. 414.

DESCRIPTION: The stoloniferous system of this species is attached to the surface of a crinoid stem. It consists of several stellate groups with numerous stolons in each, radiating from a more or less distinct central spherical cell which is about .07 mm. to .08 mm. in diameter. The stolons are nearly straight, and about .03 mm. to .04 mm. wide. The distance between the centers of the adjacent stellar groups is about 1.5 mm.

DISCUSSION: This adnate stoloniferous form is not very well preserved and probably presents an incompletely developed or partially preserved part of *Ascodictyon*. We believe that it should not be referred to the genus *Vinella* which it resembles in the development of radiating stoloniferous groups. However, the stellar groups are also typical of *Ascodictyon*. The stolons in *A.* (?) *oklahomensis* are more nearly comparable in diameter with those of *Ascodictyon* than of *Vinella* and show no tendency toward differentiation by constrictions which we regard as the most important diagnostic feature of *Vinellla*. The distinct presence of spherical cells in the centers of the radiating groups is another character typical for *Ascodictyon* but not yet observed in the undoubted species of *Vinella*.

Specifically *A.* (?) *oklahomensis* resembles *Ascodictyon* (?) (*Vinella*) *radiciforme* var. *conferta* (Ulrich) in the size of the stolons and the apparent presence of the "nuclei" in the centers of the radiating groups. However, in the latter species the radiating groups are spaced closer than in *A.* (?) *oklahomensis* and have only about half as many stolons in a group.

OCCURRENCE: On crinoid stem in the Nebraska City limestone, Wabaunsee group of the Pennsylvanian subsystem. Collected from road cut 2½ miles east of Foraker, Oklahoma.

Ascodictyon youngi Vine

(Plate 5, figures 21, 22)

1891. *Ascodictyon youngi*, VINE, Yorkshire Geol. Polytech. Soc., Pr., n. ser., vol. 12, p. 90, Pl. 4, figs. 3, 4.

1904. ——, ULRICH AND BASSLER, Smithson. Misc. Quart., vol. 45, p. 289.

DISCUSSION: Ulrich and Bassler (1904) quote the original description of this species by Vine as follows:

"Zoarium composed of pyriform vesicles occasionally disposed in stellate clusters, similar to other species already described. The vesicles are connected together by filamentous, hollow, unornamented threads, which creep along and undulate with the irregularities of the surface to which they are attached. The type species is adnate to a portion of crinoid stem (*Platycrinus* sp.) and the stellate vesicles are not so abundant in their colonial growths as in the Silurian species."

Evidently the preceding description does not distinguish this from other Ascodictyons. Rather, it is a generic diagnosis and all we really have to show the features of the species is the accompanying figure prepared by Vine. We reproduced this as Figures 21 and 22 of Plate 5.

OCCURRENCE: Carboniferous shales, Hairmyres, Scotland.

Ascodictyon sparsum Ulrich and Bassler

(Plate 5, figure 20)

1904. *Ascodictyon sparsum*, ULRICH AND BASSLER, Smithson. Misc. Coll., vol. 45, No. 1452, p. 289, Pl. LXVIII, fig. 15.

TYPE: Cat. No. 43142, U. S. Nat. Museum.

The authors of this species say that the vesicles are ovate,

"appearing as highly inflated bulbs lying close to, in some instances apparently in contact with one of the extremely fine threads that run in every direction over the surface of the *Polypora*, though mostly parallel with the length of its branches. Generally the vesicles are solitary; sometimes, however, they occur in pairs, while the interval between them is often greater than shown in our figures. In size they vary from 0.1 mm. by 0.15 mm. to 0.2 mm. by 0.25 mm."

The authors further state that

"Belonging to the section of the genus having solitary vesicles, this species need only be compared with Vine's *A. filiforme*. From this species it is readily distinguished by the smaller size of its vesicles and greater delicacy of its connecting threads."

OCCURRENCE: Near top of Chester group, Claxton, Caldwell Co., Kentucky.

Ascodictyon parvulum Ulrich and Bassler

(Plate 5, figure 19)

1904. *Ascodictyon parvulum*, ULRICH AND BASSLER, Smithson. Misc. Coll., vol. 45, p. 288, Pl. LXVIII, fig. 14.

TYPE: Cat. No. 43143, U. S. Nat. Museum.

The original description of this form is as follows:

"This species is characterized by its extreme minuteness and crowded habit of growth. Five to eight vesicles occur in each cluster, but in parts of the colonies they appear to be arranged without regard to any central point or points. As a rule these irregularly disposed vesicles are of less than the average size. Generally the vesicles are elliptical or pyriform in outline, and vary in length from 0.07 to 0.12 mm."

OCCURRENCE: Chester group, Jackson County, Kentucky.

Genus *Vinella* Ulrich, 1890

1890. *Vinella*, ULRICH, Cincinnati Soc. Nat. Hist., Jour., vol. 12, p. 173–174.
1892. ——, MILLER, *North American Geology and Paleontology*, First Appendix, p. 685.
1892. ——, VINE, Yorkshire Geol. Polytech. Soc., Pr., n. ser., vol. 12, p. 84.
1895. ——, ULRICH, Minn. Geol. Nat. Hist. Survey, vol. 3, p. 112–115, Pl. 1, figs. 1–5.
1895. ——, SIMPSON, N. Y. State Geol., 14th Ann. Rept. for 1894, p. 604, Fig. 222.

1900. *Vinella*, (part) NICKLES AND BASSLER, U. S. Geol. Survey, Bull. 173, p. 19.
1904. ——, (part) ULRICH AND BASSLER, Smithson. Misc. Coll., vol. 45, p. 273, Pl. LXVIII, figs. 1–3 only.
1913. ——, BASSLER, *in* ZITTEL, *Textbook of Paleontology*, 2d English ed., Vol. 1, p. 317, Figs. 437 B, C.
1935. ——, TWENHOFEL AND SHROCK, *Invertebrate Paleontology*, p. 232, Fig. 80 D, E.

GENOTYPE: ***Vinella repens*** Ulrich (by Ulrich's original designation).

The original species of *Vinella* was found attached to the inner surface of a ventral valve of *Strophomena septata* Winchell and Schuchert, (originally identified by Ulrich as *Streptorhynchus filitextus* (Hall) from the *Phylloporina* beds of the Black River formation, Middle Ordovician (Trenton), at St. Paul, Minnesota. The new species which we describe as *V. ulrichi*, is from the Jacksboro limestone, Upper Pennsylvanian of Texas.

DIAGNOSIS: As the result of our analysis of the genotype of *Vinella*, and its comparison with other genera of the Ctenostomata, we characterize this genus as follows: Zoarium consists of creeping or embedded stolons of nearly uniform moderate thickness, with localized tendency of differentiation into segments by constrictions and with the development of circular openings in a single row along the upper surface; openings spaced at intervals corresponding to the spacing of the constrictions, so that there is one ope ning for each differentiated segment. Occasional grouping of stolons (five in the only example illustrated) in clusters radiating from a common small central plate, apparently differentiated from the stolons by more or less distinct constrictions.

DISCUSSION: Originally only the single species, *V. repens* was described (Ulrich, 1890, p. 173–174) from this genus and designated as the genotype. Therefore this species must be pre-eminently considered in the characterization of the genus. In the original description Ulrich (1890, p. 173) defined the genus as follows:

"Zoarium attached to foreign bodies (shells, etc.), consisting of exceedingly slender, ramifying, thread-like tubes, occasionally arranged in a radial manner. Surface of tubes often faintly lined longitudinally. A row of widely separated small pores along the center of the surface of the tube. Zooecia unknown. Type: *Vinella repens* n. sp." Ulrich says:

"As interpreted by me, the fossils for whose reception this genus is proposed represent the stoloniferous part of the bryozoan only. The zooecia I regard as having been deciduous, and developed by budding from the creeping stolons at the points now represented by the small pores."

This definition of *Vinella* is now augmented by the following based on our additional observation on the genotype and on our new species, *V. ulrichi*.

In the analysis of the morphology of the fossil Ctenostomata and its relation to taxonomy we already emphasized the importance of the manner and degree of differentiation of the stolons for taxonomic classification. In the single specimen on which the species *Vinella repens* is established we observe an interesting local change of some of the tubular stolons from solid to differentiated state by the development of constrictions and formation of fusiform segments or links. The spacing of the segments thus differentiated shows definite, simple relationship to the "small pores" of Ulrich which are arranged in a single row and are "widely separated" (*see* Ulrich's original definition of the genus cited above): each segment is provided with only one "pore." This tendency to occasional regular segmentation is not mentioned in the just quoted original generic definition of *Vinella* nor in the specific description of *V. repens* but it is clearly indicated on the original sketch of the genotype. However, the importance of this feature becomes at once evident when we compare analytically *Vinella* with *Allonema* which Ulrich and Bassler consider closely related to *Vinella* and with which we agree. In *Allonema* we have the same kind of differentiation of stolons into segments or links. The difference of segmentation in the two genera seems to be not in the manner but only in degree: in *Vinella* differentiation into segments is occasional and incomplete, while in *Allonema* it is constant and nearly always complete.

Although in the original generic definition of *Vinella* the stolons are characterized as "exceedingly slender," their diameter for the genotype is given by Ulrich (1895, p. 114) as .06 to .11 mm., which is not far from the diameter of the sausage-shaped links or segments in most species of *Allonema*: .25 mm. in *A. botelloides*, .1 to .15 mm. in *A. botellus*, and .1 in *A.* (?) *minimum*. On the other hand in *Vinella* the stolons are arranged "in radial manner" (Ulrich, 1895, p. 112) while this is not the case

with the segments or their aggregates in the known species of *Allonema*. However, we now describe the new species *Vinella ulrichi*, which shows no radial arrangement of the stolons, and the latter are partially entire as in *Vinella* and partially differentiated into segments as in *Allonema*. It may be argued that because this new species shows no radial arrangement of the stolons it should not be classified with *Vinella*. On the other hand if we classify it with *Allonema* we will have to expand the generic meaning of the latter to include partially segmented stolons which we consider characteristic of *Vinella*. Furthermore, in our new species of *Ascodictyon*, *A. nebraskensis*, the stolons are radially arranged, which demonstrates that this type of arrangement of stolons cannot be considered exclusive for the genus *Vinella*. We feel justified, therefore, in the redefinition of the genus *Vinella* to put emphasis on the character and degree of differentiation of the stolons instead of their casual radial arrangement. Of course this redefinition does not change the genotype, but it results in the reclassification of several species which formerly were included provisionally in *Vinella*. Those which show only radial arrangement of stolons but no other structural features may be referred either to *Vinella* or to *Ascodictyon*, and, in the light of our analysis of these two genera, if they show no tendency for segmentation of the stolons by constrictions or development of rows of scars, they may be classified with the latter rather than with the former.

Therefore we attempt to revise the classification of the known fossil Ctenostomes which were previously classified with *Vinella* primarily on the ground of having stolons in starlike aggregates. We find that none of them could be placed in the genus *Vinella* without some reservations, while a few definitely do not belong there and should be retained in *Ascodictyon* with which they were originally classified. Such are the following forms from England: the lower Carboniferous *Ascodictyon radians* Nicholson and Etheridge, Jr. (Pl. 5, figs. 11–13). and the Silurian *A. radiciforme* Vine (Pl. 5, figs. 1–6). Both of these show the method of differentiation of the stolons into vesiclelike links through gradual swelling which produces fusiform segments. Furthermore the openings arranged in single row in both species are very densely spaced: about 30–32 in 1 mm., as measured by us on the corresponding sketches by Vine and by Nicholson and Etheridge, Jr. Thus they must be interpreted as pores and should not be considered scars of attachment of zooecia or homologous structures, which are observed in the genotype of *Vinella*. In both of the English species there may be observed a few finer tubes which show no tendency to swell into vesiclelike forms but are apparently normal stolons which probably connect the starlike groups of variously modified and partially swelled thicker tubes. It may be pointed out that, judging from the illustration of the genotype of *Vinella*, its stolons are, on the contrary, nearly uniform in thickness, becoming much more thin only at the short constrictions.

Among the three other species Ulrich and Bassler placed in this genus, *V. radiciformis* var. *conferta* (Pl. 5, figs. 9, 10) shows all the features typical of the stoloniferous system of *Ascodictyon* stripped of the vesicles. We have several examples of *Ascodictyon nebraskensis* n. sp. with no vesicles developed or preserved. Both in the uniform thinness of the stolons and in the spacing of the pores, which are shown on the sketch but not described, the species seems to be more like *Ascodictyon* than like *Vinella repens*.

Vinella radialis Ulrich (Pl. 5, fig. 15) is a peculiar form with starlike aggregates of unusually rigid (straight) tubes, but the preservation of the specimen is said to be "not favorable enough to show either the pores on the threads or character of the centers" (Ulrich and Bassler, 1904, p. 274–275). Even the width of these threads or tubes remains unknown and they are shown as single straight lines on the sketch. In view of this and the apparent thinness of the tubes the species seems to be of doubtful affinity and may be rather questionably referred to *Ascodictyon*.

There remains *Vinella* (?) *multiradiata* Ulrich and Bassler (1904, p. 276, Pl. LXVIII, fig. 8), the unusual features of which are pointed out by the authors, who call it a "supposed *Vinella*." However, it is not certain that this species should be retained among the fossil ctenostomes, and its classification with *Vinella* is indeed entirely tentative.

Vinella ulrichi n. sp. has characteristics intermediate between those of *Allonema* and *Vinella*, but we believe that it is closer to the latter. Its stolons are uniform in size and are in part solid but grade laterally into stretches with distinct annulations and finally into beadlike differentiation, each beadlike segment with a conspicuous single scar. These stolons are not radially arranged, but in *Vinella repens* we observe that of its two "zoaria" which are developed on a single brachiopod shell,

only the larger one has a single star-shaped group of stolons, while in the smaller zoarium there is none. The stoloniferous system of our species is more nearly comparable in size to the smaller "zoarium" of *V. repens*, in which no starlike clustering of the stolons is developed, and we consider this another indication of the casualness of the starlike arrangement of stolons in *Vinella*.

Vinella ulrichi n. sp.

(Plate 7, figures 1–3)

HOLOTYPE: Nebraska Geol. Survey, No. 422 C. Schuchert's Texas Collection, No. 3506/5.

DESCRIPTION: This species, named in honor of E. O. Ulrich, consists of stolons which are mostly embedded in *Composita subtilita* shells but are partly exposed when they run along and under the edge of the shinglelike overlap of the successive major growth stages of the *Composita* shell. The stolons are usually regularly curved, and occasionally branching but do not form radiating groups. The stolons are normally in the form of tubes with uniform .20 to .25 mm. diameter, with surface smooth to covered by numerous transverse wrinkles. These simple tubes grade laterally into intensive beadlike portions through the development of regular transverse constrictions. In each beadlike segment thus differentiated there is one, round to crenulated, central scar which faces upward. The scars are usually somewhat elevated and have a central depression. The rows of the elevated scars puncture the outer thin layer of the *Composita* shell and appear on its surface as curved rows of small somewhat crenulated ringlets. The spacing of the beadlike segments and the corresponding scars, though more or less regular, varies within short distances from about 5 to 8 segments in 1 mm. Another modification of the normally tubular stolons occurs when they enter the narrow space between the two successive major stages of the *Composita* shell. Here they become transversely expanded parallel to the surface of the shell and the expanded upper and lower flat surfaces thus formed are usually marked by two or three sharp longitudinal depressions, which seemingly indicate the original contacts of several stolons which fused together in parallel position, similar to grown together stolons in *Vinella repens* (Pl. 6, fig. 4). The transverse outline of these flattened stolons is nearly rectangular, the two shorter sides being also somewhat flattened, but generally irregular and rugose. The outer part of the stolons is made of dark-brown hard limonite, and the inner is filled by soft ochreous clay.

DISCUSSION: In the thickness of the stolons and the manner of their differentiation the species may be compared with *Vinella repens* and *Allonema*. Its stolons grade from simple to regularly differentiated tubes not unlike in *Vinella repens*, but in the latter the differentiated segments are fusiform while in *V. ulrichi* they are beadlike. This form of segment in *V. ulrichi* is much like that in most species of *Allonema*, but in the latter genus their differentiation is more complete and only a few segments occasionally fuse together to form a continuous tube with only faint traces of constriction. In the immergence of most stolons this species is unlike either *Vinella* or *Allonema* and may be compared with the immerged species of *Heteronema*, but it differs from the simple tubes of the latter in the frequent differentiation of its tubes into segments. Similarities between *V. ulrichi* and the various species of *Vinella*, *Allonema*, and *Heteronema* seem to indicate that these three genera are probably closely related and belong to one family, as already suggested by Ulrich and Bassler.

OCCURRENCE: The holotype is embedded from the outer side in both valves of a *Composita subtilita* shell, from the Jacksboro limestone, Cisco group, Pennsylvanian; found 3½ miles southeast of Jacksboro, Texas.

Genus *Allonema* Ulrich and Bassler, 1904

1884. *Rhopalonaria*, (part) VINE, Ann. Mag. Nat. Hist., 5th ser., vol. 14, p. 85, figs. IV, 3 only.
1885. ——, (part) VINE, Yorkshire Geol. Polytech. Soc., Pr. n. ser., vol. 9, p. 185, Pl. 12, fig. 11, (?12).
1904. *Allonema*, (part) ULRICH AND BASSLER, Smithson. Misc. Coll., vol. 45, p. 279–285, Pl. LXV. fig. 14; Pl. LXVII, figs. 1–7, 9–12 only.
1906. ——, BASSLER, U. S. Geol. Survey, Bull. 292, p. 13, Pl. IV, fig. 9.

GENOTYPE: *A. botelloides* Ulrich and Bassler.

DIAGNOSIS: The genus was characterized by Ulrich and Bassler (1904, p. 280) as follows:

"Fossil zoaria of which only the creeping base is known. This attaches itself to foreign bodies and consists of strings of sausage-like bulbous fusiform or pear-shaped internodes or vesicles varying greatly in size in different species. Surface of internodes minutely punctate, while a number in each colony exhibit a large pore-like depression, usually near one end of the vesicle or internode that is regarded as marking the point where zooecia were attached."

DISCUSSION: We discuss the general relationship of *Allonema* to *Vinella* under the latter genus and in view of the fact that we describe only one new and rather typical species of the genus we do not feel justified in adding anything to its characteristic as given by Ulrich and Bassler. However, we exclude from *Allonema* the species *Ascodictyon fusiforme* Nicholson and Etheridge, Jr., because the latter was designated as genotype of *Ascodictyon* by Ulrich, 1890.

When making a decision as to whether a species belongs to *Ascodictyon* or *Allonema*, we suggest that the most critical feature among those considered should be communication scars. No communication scars have been observed in the known species of *Ascodictyon*, while in *Allonema* there is one scar for each segment of the differentiated stolon. However, when the wall of these segments is not preserved the scar becomes obscure to indistinct. In this case the sausagelike to beadlike form of the segments is sufficiently diagnostic for a reference of a species to *Allonema*. However, when communication scars are not preserved and the segments are fusiform, their generic reference is disputable, because in some cases the segments of true *Allonema* are approaching fusiform shape (Pl. 6, fig. 15). On the other hand, when fusiform segments have preserved pores and in the same time show no communication scars they may be reasonably referred to *Ascodictyon* and not to *Allonema*.

Allonema globiforme n. sp.

(Plate 8, figures 1–3)

HOLOTYPE: Nebraska Geological Survey No. 415. (*See* Occurrence.)

DESCRIPTION: "Zoarium" prostrate, composed of straight chain of beadlike segments, frequently bifurcating at an angle about 60°–70°. Segments about .2 mm. wide and .20 to .25 mm. in length, separated by constrictions or nodes about $\frac{1}{4}$ to $\frac{3}{4}$ the width of the segments. The fossilized remains seem to be the internal molds of original segments, with surface somewhat granular but without clearly outlined pores or zooecial apertures.

DISCUSSION: This form is referred to *Allonema* with a considerable degree of confidence because of its typical simple zoarium which resembles a string of beads. It is nearest to *Allonema minimum* Ulrich and Bassler from the Upper Pennsylvanian of Illinois in the globular shape of zooecia and general linear growth with occasional bifurcation, but differs in having zooecia twice as wide as in *A. minimum*.

OCCURRENCE: Attached to outer wall of lophophyllid coral, in the Beil limestone, Shawnee group, Pennsylvanian. From a new quarry just west of the Snyderville quarry, about 3½ miles west and 1 mile north of Nehawka, Nebraska.

Allonema ? minimum Ulrich and Bassler

(Plate 6, figures 10–12)

1904. *Allonema ? minimum*, ULRICH AND BASSLER, Smithson. Inst. Quart. 45, p. 284–285, Pl. LXVII, figs. 11–12.

TYPE: Cat. No. 43124, U. S. Nat. Museum.

DESCRIPTION: In this form the stolons are described as being segmented into subglobular to pyriform vesicles with scars on the latter. Its systematic position is questionable.

OCCURRENCE: Upper Coal Measure. Springfield, Illinois. According to communication from Dr. H. R. Wanless of the University of Illinois the horizon of occurrence corresponds to the basal part of the Missouri series.

INSERTAE SEDIS

GENERAL STATEMENT

The genera *Bascomella*, *Heteronema* and *Rhopalonaria* are placed under *Insertae sedis* because their relationship to the living ctenostomes is regarded with doubt, and our investigation also causes us to adopt a cautious attitude toward an unreserved classification of these genera with the Ctenostomata. Hence, though we follow the customary description of these forms with the ctenostomatous Bryozoa, we consider this classification provisional. The reasons for our attitude are explained in the following discussions, in which the various possibilities of their classification are explored.

Genus *Bascomella* Morningstar, 1922

(Emend., Condra and Elias)

1922. *Bascomella*, MORNINGSTAR, Ohio Geol. Survey, Bull. 25, p. 156–158, Pl. IV, figs. 18–20.

DIAGNOSIS: Zoariumlike system prostrate, consisting of tubular stolons and vesicles embedded in the medium of attachment; stolons moderately thin, sparsely branching, without radial arrangement; vesicles large, oval to pear-shaped with pedestal-like basal part, probably connected singly or in irregular groups to the stolons; attached to stolons at a point usually near their narrow end; presence of pores or larger openings on vesicles or stolons not definitely established.

GENOTYPE: *Bascomella gigantea*, Morningstar, 1922.

DISCUSSION: Because we have in our collection numerous specimens which are apparently identical with *Bascomella* but are in a somewhat different, and in some respects, a better state of preservation than the original material studied by Morningstar, we found it desirable to make a comparative study of her material and ours. Thanks to the courtesy of Professor J. Ernest Carman, Chairman of the Dept. of Geology at Ohio State University, we received from him "the three best specimens" among the 12, all of which were "marked as cotypes" (Carman, written communication, 1940) and deposited at the University. The three specimens loaned to us have about equally well-developed *Bascomella* structures, all being attached to the inner side of external casts of *Spirifer boonensis*, as identified and described by Morningstar (1922, p. 158). However on none of them can the exact pattern of stolons and vesicles, as shown on Figure 18 by Morningstar (our Plate 6, fig. 20), be recognized. As Professor Carman explains in his letter this drawing "is a composite rather than an exact drawing of one specimen." In view of this we selected and photographed the best specimen of the three and designate it now as the type (lectotype) specimen of *Bascomella gigantea*, Ohio State University No. 19345, which is the genotype of *Bascomella*, as designated by Morningstar.

The original description of the genus *Bascomella* by Morningstar (p. 156–157) is as follows:

"A parasitic, boring bryozoan which has been assigned to the family *Rhopalonariidae* of the Order *Ctenostomata*. Zoarium creeping, branching, partially or entirely embedded in the host; composed, as far as is known, of relatively large ovoid, pear-shaped, or fusiform bodies or internodes, without regular arrangement, connected by minute, branching tubular filaments or stolons. Internodes marked by a few rather large pores scattered irregularly over the surface. Zooecia unknown, but probably deciduous and developed by budding from the surface pores as in the genus *Rhopalonaria*."

The material on which this description is based is in the form of internal molds of vesicles and stolons attached to external casts of the outer side of *Spirifer boonensis* valves. The matrix which fills these molds is soft sandstone with a thin crust of limonite covering the surface of the molds. The limonite of the crust, though very thin (about .05 mm.) tends to slightly obscure the details of the structure of the molds and, furthermore, develops its own inorganic structure. Thus it seems that the remark by Morningstar about the "internodes marked by a few rather large pores scattered irregularly over the surface" (1922, p. 257) refers to the features developed inorganically in the limonitic crust. Although pores and openings indeed could be developed on vesicles of *Bascomella*, as they are occasionally observed on similar vesicles of other ctenostomes, their presence in *Bascomella* must be considered doubtful. Their irregular scattering, as described and sketched by Morningstar is unlike the arrangement of smaller pores in the vesicles and stolons of *Ascodictyon* and *Vinella*, nor

does it correspond to the position of communication scars which have been observed in *Allonema*, *Rhopalonaria*, and related forms.

There are no remnants of the calcareous shell of *Spirifer* in the casts to which *Bascomella* is attached and the contention that its zoarium is "partially or entirely embedded in the host" is also an inference. This inference, however, is justified because being based on the fact that the mold of the zoarium, as now observed, is closely and firmly adherent to the cast or impression of the outer surface of *Spirifer* shell, and is facing inside of the shell. When allowance for the thickness of the original *Spirifer* shell is made it becomes clear that the zoarium of *Bascomella* must have been embedded in it, at least in its basal part. Exactly how large a part of the zoarium was thus embedded is not easy to conclude, hence the guarded statement by Morningstar that it was "partially or entirely embedded." However, we have evidence from our material of the genus in Nebraska, that vesicles were completely immersed in the substance of the shell, while stolons are also immersed or may be adnate.

The combination of the stolons and vesicles in *Bascomella* resembles that of *Ascodictyon* but differs from the latter in the larger size of both stolons and vesicles, in the absence of radiating, stellar arrangement of either of these elements, and in the development in the vesicles of pedestal-like bases immersed in the supporting medium.

As we extend our comparative studies over other genera of the Paleozoic Ctenostomata we find that the stoloniferous system of *Bascomella* without the vesicles can be hardly differentiated from that of *Heteronema*. In our ample material from the late Paleozoic of Nebraska there are specimens of stoloniferous systems with only a very few or no vesicles attached. It appears that as a rule when stolons are crowded into dense aggregates, like that here illustrated in Figure 6 of Plate 7, or as represented by the genotype of *Heteronema* illustrated by Ulrich and Bassler (1904, Pl. XLV, fig. 11; our Pl. 6, fig. 17), vesicles are not developed. However, even when the vesicles of *Bascomella* are found in dense aggregates, the connecting stolons, though generally not crowded, are at some points crowded nearly as dense as is customary for *Heteronema*. Thus it appears that the genera *Bascomella* and *Heteronema* cannot be sharply separated and seem to be but different stages of development or merely variously preserved parts of the same type of prostrating Bryozoa (if their reference to Bryozoa is correct), the complete zoarium of which is unknown. If both generic names are to be employed, which seems to be advisable, the only way in arbitrary differentiation between the two appears to be as follows: when only stolons are developed or preserved this type of fossil structure is referrable to *Heteronema*, but when vesicles are present it should be referred to *Bascomella*. That is *Bascomella* is a more nearly complete development of the zoarium than *Heteronema*. Most *Bascomella* "vesicles" appear as dentlike casts in various shells and other fossils.

For comparison of the *Bascomella* with some excavations in living shells *see* discussion under *Rhopalonaria*.

Bascomella gigantea Morningstar

(Plate 6, figures 20–22; Plate 9, figures 3–5; 7–8; Plate 10, figures 4–11; Plate 11, figures 1–6)

1922. *Bascomella gigantea*, MORNINGSTAR, Ohio Geol. Survey, Bull. 25, p. 157–158, Pl. VI, figs. 18–20.

HOLOTYPE: Geological Museum, Ohio State University No. 18345. On the inner side of the external cast of *Spirifer boonensis* valve from the lower McArthur limestone, Pottsville series, Pennsylvanian subsystem. At Monroe Furnace, northern part of Sec. 29, Jefferson Township, southern part of Jackson County, Ohio.

DESCRIPTION: The original description of the species by Morningstar (1922, p. 157) is as follows:

"Zoarium creeping, partially, or, as is generally the case, entirely embedded in the host, sometimes covering the entire inner surface of the shell on which it is parasitic. Ovoid bodies typically pear-shaped but often fusiform or irregular in outline; arrangement irregular; narrow pointed and depressed, broad blunt end constricted near base; formed by the filling of the excavation with sediment; an ovoid body of average size measuring: length 2 mm., width .8 mm., height 1 mm.; surface apparently pierced by rather large, distant, irregularly arranged pores. Minute, tubular filaments or stolons connected with any portion of the ovoid bodies, but generally with the base; one or several growing from each excavation; branching frequently and forming an irregular network."

Our description of this genus, based on both the original material from Ohio and the new material from Nebraska, is as follows: Stolons about .15–.18 mm. thick, entirely adnate or partially to nearly completely embedded in the supporting shell; occasionally branching at angle varying from about 45° to nearly 90°. Vesicles variable in size apparently representing stages of development; mature vesicles of about uniform size, about .8–.9 mm. wide, 2 mm. long and up to 1 mm. high (or thick). Viewed from above they are elongately ovoid to pyriform in shape; the narrower end sloping to a fairly sharp point. In the side view the mature vesicles are seen clearly to grade into a solid foundation which occupies the space as outlined by the shape of the vesicles. The smaller, immature vesicles show only a very slight broadening at the very base, after distinct downward contraction. The specimens from Nebraska are apparently adnate upon the shell of *Myalina* but actually they were embedded in the shell, the inner ostracum of which (probably made of aragonite) became dissolved, and only the outer ostracum is left, upon which they are adnate.

The radiating arrangement of stolons was observed but once (Pl. 11, fig. 3), but there is no initial spherical cell in the center of this group and perhaps this radiating arrangement is incidental.

The connection of the vesicles to the stolons apparently takes place not at their sharp ends but at some point along the slanting slope and is accomplished by a thin anastomosing neck, which is usually not preserved.

Discussion: In our comparative analysis of the types, on which this description is based, and of the specimens from Nebraska, it is shown that the stolons are in some cases nearly completely embedded in the supporting shell, while the vesicles ("ovoid bodies" of Morningstar) are always completely embedded. We found no certain evidence of pores or other openings or scars on the vesicles or stolons, both of which are represented by the internal molds. These molds are encrusted by thin limonitic film which bears various minute sculpture, the origin of which may be wholly inorganic.

In our specimens the stolons and vesicles are likewise represented by the internal molds, and on these no marks of any kind can be observed. The specimens from Nebraska are so close to the originals from Ohio in the general character of the stoloniferous system, the size of the stolons, and the size and shape of the vesicles that we see no reason for specific separation of our form: the difference between the two is only in the degree of the development of the vesicles, which form much more crowded groups of more nearly uniform vesicles in the Ohio specimens. In the specimens from Nebraska only a few vesicles are developed in each stoloniferous system, and these are not bunched as close together as in the specimens from Ohio. In the specimens from Nebraska the vesicles and the connecting stolons are nearly always developed, side by side with the somewhat similar structures of *Caulostrepsis dunbari* n. sp., resembling pumpkin or watermelon seeds. Care must be taken in distinguishing *Bascomella* vesicles from the immature development of *Caulostrepsis*, some of which are of nearly the same size as the vesicles of *Bascomella*.

The vesicles of *Bascomella* resemble the typical vesicles of *Ascodictyon*, but are larger and have broad bases, which are unknown in the vesicles of the latter genus.

The simple systems made of stolonlike tubes of the same diameter and manner of ramification as in *Bascomella* but without vesicles attached to them, are classified by us arbitrarily with *Heteronema* as they are in no way different from the known species of this genus.

Other Occurrences:

(1) In small lophophyllid coral of the Hogshooter (Winterset) ls., Pennsylvanian. At Lost City quarry, S. of Arkansas River, a few miles west of Tulsa, Oklahoma.

(2) In *Myalina* sp. Upper part of Farley limestone, Kansas City group, Pennsylvanian. At Dyson Hollow, west of La Platte, Nebraska.

(3) In *Myalina* sp. Bonner Springs shale, Kansas City group, Pennsylvanian. At Ash Grove Cement Company quarry, Louisville, Nebraska.

(4) In *Myalina* sp. Stanton formation, Lansing group, Pennsylvanian. Mound at northwest edge of Bartlesville, Oklahoma.

(5) In *Pseudomonotis equistriatus* and in *Myalina* sp. Base of Cass limestone, Douglas group, Pennsylvanian. About 2 miles northwest of Nehawka, Nebraska.

(6) In *Neospirifer triplicatus*. Cass limestone, Douglas group, Pennsylvanian. About 2 miles northwest of Nehawka, Nebraska.

(7) In *Neospirifer triplicatus* and *Stenopora* sp. Top of Cass limestone, Douglas group, Pennsylvanian. Burlington quarry, about 2 miles northwest of South Bend, Nebraska.
(8) In *Neospirifer triplicatus*, *Echinoconchus* sp., and *Linoproductus* sp. Cass limestone, Douglas group, Pennsylvanian. Southeast of Ashland, Nebraska.
(9) In *Neospirifer triplicatus*. Plattsmouth limestone, Shawnee group, Pennsylvanian. Snyderville quarry, about 3 miles west and 1 mile north of Nehawka, Nebraska.
(10) In *Myalina slocomi*. Doniphan shale, Lecompton formation, Shawnee group, Pennsylvanian. Snyderville quarry, about 3 miles west and 1 mile north of Nehawka, Nebraska.
(11) In *Linoproductus prattenianus*. Graham formation, Cisco group, Pennsylvanian. Two and a half miles west of Lacosa, Texas (coll. by C. Schuchert).
(12) In *Myalina subquadrata*. In talus slope above Willard shale, Wabaunsee group, Pennsylvanian. Creek bank southeast of Willard, Kansas.
(13) In *Myalina subquadrata*. Wamego shale formation, Wabaunsee group, Pensylvanian. RR cut 2 miles east of Maple Hill, Kansas.
(14) In *Myalina* sp. Dry Creek shale, Wabaunsee group, Pennsylvanian. West side of sec. 29, T. 13 S., R. 14 E., 5–6 miles southwest of Dover, Kansas.
(15) In *Myalina subquadrata*, *Linoproductus* sp., and *Derbya* sp. Nebraska City limestone, Wabaunsee group, Pennsylvanian. East of St. Mary's, Kansas.
(16) With *Caulostrepsis dunbari* in *Myalina* sp., Aspinwall limestone, Admire group, Permian. Three miles east of Foraker, Oklahoma.
(17) In *Neospirifer triplicatus*. Upper part of Foraker limestone, Admire group, Permian. Near Foraker, Oklahoma.
(18) In *Myalina* sp. Wreford limestone, Chase group, Permian. Quarry northwest of Strong City, Kansas.

Also in many other localities, widely distributed in the shells of larger pelecypods, brachiopods, encrusting Bryozoa and other invertebrates in the Pennsylvanian and Permian rocks of the Mid-Continent. Observed as casts in the illustrations of many shells of *Myalina* and other Mytilacea in Newell (1942). Newell described such shells as "perforated" (p. 102).

Bascomella fusiformis n. sp.

(Plate 10, figures 12–14)

HOLOTYPE: Nebraska Geological Survey No. 448. In the ventral shell of *Linoproductus prattenianus*. From Cass limestone, Douglas group, Pennsylvanian, 1 mile southeast of Ashland, Nebraska.

DESCRIPTION: In this species the stoloniferous system is entirely immersed in the shell of *Linoproductus*. The vesicles are known only as casts in this shell and appear on its surface as narrow fusiform scars, one end of which is usually slightly sharper than the other. The stolons are likewise immersed in the shell, and appear as empty casts or as molds filled by secondary calcite. There is no regularity in the orientation or arrangement of the vesicles and stolons.

The squeeze or replica (Pl. 10, fig. 13) prepared from the holotype shows how the vesicles would look if preserved. The mature vesicles are about .4 mm. wide, 1.5 mm. long, and .5–.6 mm. high. The diameter of the stolons is about .1 mm.

DISCUSSION: This species is very much like *Bascomella gigantea* but differs in the shape of the vesicles, in the lesser variability of their shape, and in their smaller size. The diameter of the stolons is about the same in both species.

OTHER OCCURRENCES: In lophophyllid coral. Basal part of Iatan limestone in abandoned brickyard just north of Fort Leavenworth, Kansas.

Bascomella subsphaerica n. sp.

(Plate 12, figure 1)

HOLOTYPE: Nebraska Geological Survey No. 449. Within the cast of a shell of *Rhipidomella hessensis* from the upper part of the Kaibab limestone; Permian system, near Bright Angle trail just west of Grand Canyon, located 50 miles north of Williams, Arizona.

DESCRIPTION: This small *Bascomella* was discovered in the course of the study of invertebrates collected by Condra from the Kaibab limestone at Grand Canyon, Colorado. Its stoloniferous system includes thin stolons and subspherical to slightly obovate vesicles which are found as silicified molds within the cast of the dorsal shell of *Rhipidomella hessensis* King. Both sides of the cast of the shell are preserved, the narrow space between them corresponding to the thickness of the original calcareous shell which became completely removed, probably by aqueous solution. The stoloniferous system is attached to the sides of this empty narrow space and thus was entirely immersed in the shell. Judging from the empty space the brachiopod shell varies in thickness from about .2 mm. at the distal margins to about .5 mm. at the beak. The stolons are straight or slightly curved, of uniform thickness about .04–.05 mm. The vesicles vary in size from .1 x .12 mm. to .3 x .4 mm. and are scattered without regularity in orientation or grouping.

DISCUSSION: The character and the manner of development of the stoloniferous system within a brachiopod shell suggests at once the biologic relationship of this species to *Bascomella*, but this species differs from *B. gigantea* in the shape and much smaller size of the vesicles, as well as in the smaller diameter of the stolons.

Genus *Heteronema* Ulrich and Bassler

1904. *Heteronema*, ULRICH AND BASSLER, Smithson. Misc. Coll., vol. 45, p. 266–278.
1913. ——, BASSLER, *in* ZITTEL, *Text Book of Paleontology*, 2d English ed., p. 317–318.
1922. ——, BASSLER, Smithson. Inst., Ann. Rept. for 1920, p. 355–356.
1935. ——, TWENHOFEL AND SHROCK, *Invertebrate Paleontology*, p. 231–232.

DIAGNOSIS: Zoaria incompletely known, consisting of simple, creeping stolons, adnate or partially immersed in supporting medium, straight or slightly irregularly undulate or somewhat curved, occasionally sharply turned, scarcely ramifying at moderate to nearly right angle; arranged without apparent order or when completely interconnected forming a more or less regular network; as in *H. priscum* Bassler (1922, p. 355, Fig. 6–1, 2.).

GENOTYPE: *H. capillare* Ulrich and Bassler. (*See* Pl. 6, fig. 17.)

DISCUSSION: This genus was characterized by Ulrich and Bassler (1904, p. 278 as follows: "Zoaria, so far as known, consisting of usually simple or locally jointed, sparsely ramifying, tubular, creeping threads, arranged without apparent order. Pores rarely observed, apparently always in single row."

On the ground of this diagnosis and of the inclusion in the genus of *Heteronema carbonarium* Ulrich and Bassler (1904, p. 279, Pl. LXV, fig. 13) there seems to be no doubt that the numerous threads, adnate and immersed in the various invertebrate shells which are very common in the Pennsylvanian and Permian of the Northern Mid-Continent region, should be classified with *Heteronema*. However, from our analysis of *Bascomella* it follows also that the stolons of the latter genus, when found without vesicles attached, are indistinguishable from *Heteronema*. Thus *Bascomella* should be considered a synonym of *Heteronema* providing there is no doubt that the latter is merely a stoloniferous system in which vesicles are not developed, or, merely, not preserved in fossilization. That the latter is quite possible is shown by our numerous examples of undoubted *Ascodictyon* stoloniferous systems in which vesicles are absent, *see* discussion of *Ascodictyon*. However it appears quite possible that at least some of the simple stoloniferous systems included by Ulrich and Bassler in *Heteronema* did not develop vesicles, as these authors understood when they introduced the genus *Heteronema*. They say that they understand *Heteronema* as "the most simple type of the family" Vinelliidae and distinguished from *Vinella*, which is the nearest to it "because of its extremely simple structure, and partially on account of the absence of the highly characteristic nuclei, and consequent radial arrangement of the threads of *Vinella*[2]" (Ulrich and Bassler, 1904, p. 278).

In view of this it seems that both generic names *Bascomella* and *Heteronema* may be used, but it must now be understood that at least some of the simple stoloniferous systems of *Heteronema* type may actually belong to *Bascomella*. Others may belong to incomplete stoloniferous systems of *Ascodictyon*, accepting the latter in the sense here suggested, that is, including the stoloniferous

[2] As explained in our discussion of *Vinella* we do not consider nuclei and radial arrangement of stolons typical for *Vinella*.

systems consisting of simple vesicleless undifferentiated stolons with occasional stellar arrangements, which formerly were provisionally classified as *Vinella* (Ulrich and Bassler, 1904).

In our material from the Pennsylvanian and Permian of the Mid-Continent we find two new species of the *Heteronema* stoloniferous systems, which are distinguished from the previously described forms by appreciable difference in the diameter of the solons.

For comparison of *Heteronema* with some excavations in living shells *see* discussion under *Rhopalonaria*.

Heteronema carbonarium Ulrich and Bassler

(Plate 6, figure 19)

1904. *Heteronema carbonarium* Ulrich and Bassler, Smithson. Mics. Coll., vol. 45, p. 279, Pl. LXV fig. 13.

Type: Cat. No. 43132, U. S. Nat. Museum.

Ulrich and Bassler differentiate this species from *H. capillare*, the genotype,

"on account of the greater strength and comparative rigidity of its threads. These are also more flattened, and hold a nearly uniform width, the extremes scarcely exceeding the difference between .06 mm. and .07 mm. A slight, transverse wrinkling of the surface may be observed, but as we could not satisfy ourselves that the feature is characteristic of the species, it was not shown on our illustration."

The material on which this species was established comes from the "Lower Coal Measures" at Seville, Illinois. According to communication from Dr. H. R. Wanless of the University of Illinois the horizon of the location corresponds to the lower part of the Des Moines series.

We did not find this species in the Pennsylvanian and lower Permian rocks of the Mid-Continent where different species of *Heteronema* are fairly common.

Heteronema parvula n. sp.

(Plate 8, figures 5-8)

Holotype: Nebraska Geological Survey No. 426, in *Myalina slocomi* from Bennett, Nebraska; *see* description of locality (1) below.

Description: This species has the thinnest stolons known for the genus. The stolons or threads are straight to curved, with diameter varying from about .015 to .02 mm. Only a few specimens are in our collection. In most of them the stoloniferous systems are attached to the inner surface of the outer ostracum of large *Myalina*. In a small lophophyllid coral and in *Cladochonus* sp. from Oklahoma the threads are probably made of earthy pyrite.

Discussion: In the smallness of the diameter of the stolons the species is nearest to *H. capillare* Ulrich and Bassler, from the Silurian of Gotland, but has still thinner threads and, besides, they are not jointed to form a netlike system as in the Silurian form.

Occurrence:

(1) On inner side of inner ostracum of *Myalina* (*Orthomyalina*) *slocomi* Sayre. Hughes Creek shale, Admire group, Permian, ½ mile west of Bennett, Nebraska.

(2) On inner side of inner ostracum of *Myalina* (*Orthomyalina*) *slocomi* Sayre. Base of Wamego shale, Wabaunsee group, Pennsylvanian. In RR cut about 2 miles east of Maple Hill, Wabaunsee County, Kansas.

(3) In small lophophyllid coral and in *Cladochonus*. Lenapah formation, Marmaton group, Des Moines series, Pennsylvanian. Near Nowata, Oklahoma.

Heteronema magna n. sp.

(Plate 7, figures 4-6)

Holotype: Nebraska Geological Survey No. 423. The stoloniferous system of the holotype is nearly completely submerged in the inner part of the shell of *Myalina* (*Orthomyalina*) *slocomi* Sayre, from the Kinney limestone, Chase group, Pennsylvanian, about 3 miles east of Barneston, Nebraska.

DESCRIPTION: This is a fairly common species in the Mid-Continent and is attached to or submerged in the shells of *Myalina* and other pelecypods and less frequently on brachiopods.

The stoloniferous system consists of simple tubelike stolons or threads which branch frequently. When stolons are crossing they never fuse, but pass each other by running at slightly different levels, so that they touch each other at the points of apparent crossing. The diameter of the stolons varies from .12 mm. to .20 mm. The stolons are usually more or less straight to slightly curved. The surface of the stolons is smooth and no pores of any kind were observed on it.

DISCUSSION: This species is nearest to *Heteronema carbonarium* Ulrich and Bassler, but differs in the considerably larger diameter of the stolons which is nearly the same as in the stolons of *Bascomella gigantea*, and possibly *H. magna* is only an incompletely developed *B. gigantea*. However, it differs from the stoloniferous system of the latter by frequent bifurcation and the complete absence of vesicles.

OTHER OCCURRENCES:

(1) On crinoid stems. "*Spirifer* shale," Upper part of Des Moines series, Pennsylvanian. Sec. 26, T. 1 S., R. 3 E., Oklahoma (collected by Mr. Latta).

(2) In *Neospirifer latus*. Winterset limestone, Bronson group, Pennsylvanian subsystem. Three miles east of La Cygne, Kansas.

(3) In left valve of *Aviculopecten* sp. and *Myalina wyomingensis*. Bonner Springs shale, Kansas City group, Pennsylvanian. Ash Grove Cement Co. quarry, Louisville, Nebraska.

(4) In *Composita* and other brachiopods. Top Meadow limestone member of the Plattsburg formation, Lansing group, Pennsylvanian. At Murphy and Atwood quarries, near Louisville, Nebraska.

(5) In *Myalina* sp. Captain Creek limestone member, Stanton formation, Lansing group, Pennsylvanian. Two and a half miles southwest of Cedar Creek, Nebraska.

(6) In *Myalina slocomi*. Stanton formation. Pennsylvanian. Mound at northwest edge of Bartlesville, Oklahoma.

(7) In *Myalina slocomi*. Base of shale just above South Bend limestone, Stanton formation, Pennsylvanian. East of Platte River, opposite South Bend, Nebraska.

(8) In *Myalina* sp. Base of Cass limestone, Douglas group, Pennsylvanian. Two miles northwest of Nehawka, Nebraska.

(9) In *Myalina* sp. Doniphan shale, Lecompton formation, Shawnee group, Pennsylvanian. Snyderville quarry, 3 miles west and 1 mile north of Nehawka, Nebraska.

(10) In *Linoproductus prattenianus*. Doniphan shale, Lecompton formation, Shawnee group, Pennsylvanian. Two miles west and ¾ mile south of Rock Bluff, Nebraska.

(11) In *Myalina slocomi* and *Linoproductus*. Graham formation, Cisco group, Pennsylvanian. Two and a half miles south of Lacosa, Texas.

(12) In *Schizodus* sp. Limestone in Willard shale, Wabaunsee group, Pennsylvanian. Bluffs of Missouri river, northeast corner of Otoe County, Nebraska.

(13) In *Myalina* sp. Palmyra limestone, Wabaunsee group, Pennsylvanian. Seven miles south and 1 mile west of Pawnee City, Nebraska.

(14) In *Linoproductus* sp. Maple Hill limestone, Wabaunsee group, Pennsylvanian. Six miles south and 2½ miles east of Cook, Nebraska.

(15) In *Myalina subquadrata* and *Linoproductus* sp. Nebraska City limestone, Wabaunsee group, Pennsylvanian. About 3 miles east of St. Mary's Kansas.

(16) In *Linoproductus prattenianus*. Brownville limestone, Wabaunsee group, Pennsylvanian. Fox Creek, 1 mile south and 1½ mile east of Dunbar, Nebraska.

(17) In *Linoproductus prattenianus*. Brownville limestone, Wabaunsee group, Pennsylvanian. Along creek, east side of Humboldt, Nebraska.

(18) In *Dictyoclostus americanus*. Brownville limestone, Wabaunsee group, Pennsylvanian. Along creek, east side of Humboldt, Nebraska.

(19) In *Pseudomonotis hawni* and *Aviculopecten* sp. Aspinwall limestone, Admire group, Pennsylvanian. In RR cut 3 miles east of Foraker, Oklahoma.

(20) In *Myalina* sp. Stine shale, Wabaunsee group, Permian. Weaver farm about 5 miles southwest of Falls City, Nebraska.

(21) In *Composita subtilita*. Stine shale, Wabaunsee group, Permian. Quarry 3 miles west and 1 mile southwest of Syracuse, Nebraska.

(22) In *Myalina* and *Dictyoclostus subquadrata*. Upper part, Hughes Creek shale, Admire group, Permian. One and a half miles southeast of Bennett, Nebraska.

(23) In *Dictyoclostus* sp. Hughes Creek shale, Admire group, Permian. Yoder farm 2½ miles north of Morrill, Kansas.

(24) In *Dictyoclostus* sp. Lower part of Eiss limestone, Council Grove Group, Permian. Sec. 33, T. 1 N., R. 13 E., about 5 miles east of DuBois, Nebraska.

(25) In *Myalina* sp. About the middle of Wichita group, Permian. 2 miles northwest of Ballinger, Texas (collected by R. C. Moore).

Genus *Rhopalonaria* Ulrich

1879. *Rhopalonaria*, Ulrich, Cincinnati Soc. Nat. Hist., Jour., vol. 2, p. 26.
1882. ——, Ulrich, Cincinnati Soc. Nat. Hist., Jour., vol. 5, p. 149.
1884. ——, Vine (part), Ann. Mag. Nat. Hist., 5th ser., vol. 14, p. 34–89, Figs. IV, V only.
1890. ——, Ulrich, Ill. State Geol. Survey, vol. 8, p. 267.
1891. ——, Vine, Yorkshire Geol. Polytech. Soc., n.s., vol. 12, p. 91.
1895. ——, Ulrich, Minn. Geol. Nat. Hist. Survey, p. 113–114, Fig. 8e.
1897. ——, Simpson, N. Y. State Geol., 14th Ann. Rept., 1894, p. 603, Fig. 221.
1900. ——, Nickles and Bassler, U. S. Geol. Survey, Bull. 173, p. 19.
1904. ——, Ulrich and Bassler, Smithson. Misc. Coll., vol. 45, p. 267–268, Pl. LXVI.
1913. ——, Bassler, *in* Zittel, *Text Book of Paleontology*, 2d English ed., p. 317, fig. 437-G.
1922. ——, Bassler, Smithson. Inst., Ann. Rept. for 1920, p. 355–356, Figs. 6–6 an 6–9.
1929. ——, Bassler, *Permian Bryozoa of Timor*, p. 39–40, Pl. CCXXXV, figs. 1–3.
1935. ——, Twenhofel and Shrock, *Invertebrate Paleontology*, p. 231–232, Fig. 80-F.
1944. ——, Fritz, Jour. Paleont., vol. 18, p. 33, Pl. 13, fig. 1.

Genotype: *R. venosa* Ulrich, Pl. 12, fig. 6.

Diagnosis: Zoarium adnate, consisting of delicate, fusiform internodes of relatively uniform size and form. Zoarial pattern pinnate or interconnected multiple pinnate; pinna usually interconnected. Zoarium more or less embedded in supporting medium.

Discussion: Our specimens of *Rhopalonaria* are thought to be the replaced creeping parts of molds of original zoaria, and a question arises regarding the internodes, *i.e.*, whether they are modified zooecia or rhythmic expansions which may have supported deciduous zooecia. If the expansions are zooecia, the relations of *Rhopalonaria* may be with *Corynotrypa* of the cyclostomes, but if they are not zooecia, the relations would seem to be with the Ctenostomata. In their consideration of this question Ulrich and Bassler (1904, p. 262–263) say as follows:

> Assuming provisionally that the fusiform swellings of *Rhopalonaria* are really the zooecia, we at once are confronted with the difficulty of explaining why they seem to be without clearly defined orifices. A small spot may often be detected that looks different from the rest of the swelling, and that most probably represents some kind of orifice, but none of the numerous specimens before us is in a state of preservation good enough to establish its nature beyond doubt.
>
> "Viewing *Rhopalonaria* as the creeping base of some otherwise unknown bryozoan, the subcentral position of the orifice-like spot becomes significant, for we can now see that it corresponds in all essential respects with the creeping base of a recent *Aetea*."

Ulrich and Bassler (Plate LXV, figs. 1 and 2) show the creeping base of *Aetea truncata* (Fig. 2) and zooecia arising from *A. anguina*, (fig. 1, *see also* Pl. 1, fig. 1), and observe that:

> "At the attached end of the zooecia there is a minute perforation in the corresponding subfusiform swelling of the adnate base. The position of this perforation is generally more nearly central than terminal, and thus corresponds with the facts observed in *Rhopalonaria*. The only feature on which the known facts fail to correspond is the greater regularity of the development and arrangement of the fusiform swelling of the base in the *Rhopalonaria*. This surely cannot be of sufficient consequence to deter us from classifying *Rhopalonaria* as an ancient representation of the Aetidae and more typical Ctenostomata."

D'Orbigny (1839, p. 23, Pl. x) establishes the modern ctenostomatous genus *Terebripora* for which Fisher (1866, p. 293–313, Pl. xl) describes and figures certain species. Dollfus (1877, p. 96, Pl. 1,

figs. 1, 2), and Oehlert (1888, p. 107) describe from the Paleozoic *Terebripora capillaris*, but Ulrich and Bassler (1904, p. 271, fig. 32) class it with *Rhopalonaria*. We have studied the literature on such living genera as *Aetea*, *Terebripora*, *Arachnidium*, *Vesicularia*, *Hippothoa*, *Hypophorella*, *Hippuraria* and *Delagia* in order to determine their relations to the late Paleozoic Ctenostomata and Cyclostomata, and agree with the deductions reached by Ulrich and Bassler regarding the probable relation of typical *Rhopalonaria* to Ctenostomata. However, we are convinced that the so-called burrowing or embedding habit of growth is not a feature of *Rhopalonaria* alone and may not have much generic importance.

About 11 species of *Rhopalonaria* have been described (*see* Ulrich and Bassler, 1904, p. 267–272; Bassler, 1929, p. 39–40). The two species from the Permian of Timor described by Bassler are comparable to the typical species of this genus in the size and shape of the molds of the vesicles but show little regularity in their arrangement. We reproduced here (Pl. 9, figs. 1, 2) the photographs of these forms from Bassler's monograph for comparison with similar molds from the Mid-Continent which we classify with *Bascomella*. The two species from Timor differ from the latter in much smaller size and perhaps they show a little more regularity in arrangement. *Rhopalonaria keokukensis* Ulrich and Bassler (*see* reproduction in our Pl. 12, fig. 7) is also more comparable in size and in order of arrangement to other species of *Rhopalonaria* (for instance, *R. tenuis*, Pl. 12, fig. 8) than to *Bascomella*.

The two new species which we describe are only provisionally referred to *Rhopalonaria* for the reasons explained in their description.

Rhopalonaria graphicus n. sp.

(Plate 12, figures 4, 5; Plate 13, figure 5)

HOLOTYPE: Nebraska Geological Survey No. 430. On shell of *Chonetes granulifer*, embedded from the outer side of the ventral valve. From a thin limestone in the Hughes Creek shales, Admire group, Lower Permian, 3 miles south of Stine, Nebraska.

DESCRIPTION: Stoloniferous growth dendritic, embedded in *Chonetes granulifer*, and somewhat weathered so that its pattern appears as if it were etched on the outer surface of the shell. Because of this state of preservation only the outline of the whole structure is available for study and no details of the internodes or nodes can be observed. Stolons with irregular tripinnate branching, usually at an angle from 30° to 60°; main axis not in a straight line but turning from one direction to another at some of the points where lateral branches are departing.

Branches occasionally interconnected. Main and lateral branches structurally alike, normally about .02 mm. wide with fusiform swelling of internodes up to about .06 mm. in width. Spacing of internodes about 4 per 1 mm.

DISCUSSION: This fossil is provisionally classified with *Rhopalonaria* because it agrees with this genus in being embedded in a brachiopod shell and shows dendritic development with regular differentiation into thinner threads and fusiform swellings. However, its character of branching is much less regular than in the genotype and in the other typical species of *Rhopalonaria* (*see* Ulrich and Bassler, 1904, Pl. LXVI; our Pl. 14, fig. 7) and the main axis does not run in a straight line. Furthermore, the imperfect state of preservation does not permit us to learn about the nature of the internodal swellings.

OTHER LOCALITY: In dorsal valve of *Dictyoclostus* sp. Dover limestone, Wabaunsee group, Pennsylvanian. Cut on highway 10, southeast of Maple Hill, Kansas.

Rhopalonaria dendriformis n. sp.

(Plate 12, figures 2, 3)

HOLOTYPE: Nebraska Geological Survey No. 429. In *Septopora* base, which is attached to *Myalina* (*Orthomyalina*) *slocomi* Sayre, from a limy layer in the Hughes Creek shale, Admire group, Permian. At a cut bank of the Little Nemaha River about 1½ miles southeast of Bennett, Nebraska.

DESCRIPTION: Stoloniferous growth dendritic, embedded in the broadly spreading basal disk of *Septopora biserialis*. Central axis not differentiated. The dendritic growth usually consists of

several closely set bushy branches which grow with a slight angular divergence from a common center. The manner of growth of these bushy branches is generally by bifurcation grading into irregular pinnate type; the angle of branching is usually from about 30° to 50°. All branches are of about equal .01 mm. width, and the neighboring branches are repeatedly interconnected. Along some branches, a slight, regularly spaced fusiform swelling can be observed, but usually the swelled parts do not expand more than to about .02 mm. across, and seldom to about .05 mm. About 6 swelled segments can be counted per 1 mm.

DISCUSSION: It seems that this dendritic stoloniferous system belongs to the same type of organism as *Rhopalonaria* (?) *graphicus*, but differs from the latter in smaller size and more orderly growth, and it is embedded in a different kind of medium. The reasons for the provisional classification of this species with *Rhopalonaria* are the same as discussed under *Rhopalonaria* (?) *graphicus*.

Rhopalonaria permiana Bassler

(Plate 11, figure 1)

1929. *Rhopolonaria permiana*, BASSLER, *Permian Bryozoa of Timor*, p. 40, Pl. CCXXXXV, fig. 1.

This species was described by Bassler (1929). Figure 1 of Plate 11 is rephotographed from Bassler's report. According to Bassler, this form resembles some of the Silurian and Devonian species in its small proportions, attenuate internodes, and delicate connecting stolons, and its delicate zoarium, with four cells in 2 mm. measured along the primary branch, serves for its distinction.

OCCURRENCE: At Nael Boeam, Permian of Timor. Collection Wanner.

Rhopalonaria timorensis Bassler

(Plate 11, figure 2)

1929. *Rhopalonaria timorensis*, BASSLER, *Permian bryozoa of Timor*, p. 40, Pl. CCXXXV, figs. 2, 3.

Bassler's Figure 2 is reproduced here (Pl. 11, fig. 2) and his description is condensed to the following: Zoarium robust, pinnate; cells large, fusiform; connecting stolons short.

OCCURRENCE: Rare at Fatu Tassu near Bacing (Amarassi) and at Nael Boean in the Permian of Timor. Wanner Collection.

Rhopalonaria keokukensis Ulrich and Bassler

(Plate 12, figure 7)

1904. *Rhopalonaria keokukensis* ULRICH AND BASSLER, Smithson. Misc. Coll., vol. 45, p. 272, Pl. LXVI, fig. 1.

The authors of this species state that it is closely related to *R. tenuis*, but in *R. keokukensis* the distance from center to center of fusiform cells is slightly smaller (.5 to .6 mm.) than in *R. tenuis* (.7 to .75 mm.), and their pinnate arrangement "is less obvious" than in the latter.

TYPE: Cat. No. 43122 U. S. Nat. Museum.

OCCURRENCE: Keokuk formation, Mississippian, Keokuk, Iowa.

FORAMINIFERA

Genus Ptychocladia Ulrich and Bassler

(Plate 6, figure 10a)

1904. *Ptychocladia*, ULRICH AND BASSLER. Smithson. Misc. Coll., vol. 45, p. 289–290, Pl. LXVII, figs. 10 (part), 13.

DISCUSSION: When Ulrich and Bassler (1904, p. 289–290) described the original species of this genus they stated that its "systematic position is so doubtful, that we are scarcely willing to hazard

an opinion," and added that "possibly they are algae, or, if their branches are tubular, a point we did not succeed in determining, they may prove to belong to some of the preceding forms," that is the described ctenostomatous Bryozoa.

Our material from the Virgil and Big Blue Series of Nebraska and Kansas comprises two species of the genus which provide distinct evidence that the branches are regularly divided by transverse partitions. It seems that it is an imperfect, weathered condition of the specimens of *P. agellus* from Illinois which made Ulrich and Bassler form an opinion that the branches have "transverse wrinkles," and they sketched in this feature on the two drawings of the species illustrated (Ulrich and Bassler, 1904, Pl. LXVII, figs. 10, part, and 13; our Pl. 6, fig. 10a).

The establishment by our investigation of the presence of the regular and closely set transverse partitions provides sufficient evidence against the classification of *Ptychocladia* with the tubular ctenostomes, and leaves only two other alternative classifications, with algae or with Foraminifera.

Ptychocladia is similar to some microscopic adnate algae of discoid or prostrate type, such as *Melobesia, Zanardinia, Aglaozonia* (haploid stage of *Cutleria*), and others, but it is also similar to some living adnate *Foraminifera* having close resemblance to the encrusting algae. However, recent collection by Condra of superior specimens of *Ptychocladia* from the Tecumseh shale in Kansas provides important material for the final assignment of this genus to Foraminifera. Because of this the description of *Ptychocladia* and its species is removed from this paper and reserved for a separate article in which two species of *Ptychocladia* and a species of another genus of adnate late Paleozoic *Foraminifera* from Nebraska and Kansas will be described.

PROBLEMATICA

Genus Caulostrepsis Clark, 1908

1908. *Caulostrepsis*, CLARK, N. Y. State Mus., Bull. 121, p. 169, Pl. 12, figs. 3, 4.
1921. ——, CLARK, *Organic dependence and disease*, p. 92, Figs. 84a, b (on p. 99) (distributed at same time as part of N. Y. State Mus., Bull. 221–222).
1942. "Borings of commensal worms." NEWELL, Univ. Kans. Pub., fol. 10, pt. 2. 2, *Mytilacea*, Pl. 8, figs. 4, 5.

HISTORY: The genus *Caulostrepsis* was briefly described and named by John M. Clark in an unorthodox manner due to which it escaped attention of most paleontologists. We are indebted to Professor C. O. Dunbar for calling our attention to Clark's description and interpretation of it at the time when we consulted with him on description of *Caulostrepsis dunbari* n. sp. Dunbar discovered, but did not describe, this unusual fossil from the Pennsylvanian of Nebraska in about 1929, when he was with the Nebraska Geological Survey. Since then this fossil became known among a few local paleontologists as the watermelon or pumpkin seedlike structures on *Myalina* shells.

Because Clark's original *Caulostrepsis* is a fossil from the Devonian of Germany and was illustrated by sketches only, doubt existed whether our Pennsylvanian form is congeneric with it. Doctor Winifred Goldring informed us that only one of the two types illustrated by Clark is in the collections of the New York State Museum at Albany; Dunbar examined it and compared it with our fossil material sent to him. His conclusion is that the fossils are congeneric. The photograph of Clark's type was kindly supplied by Goldring and is published here (Pl. 11, fig. 7).

LECTOTYPE: Because there were two original specimens illustrated by Clark without designation of type we select the specimen deposited at the State Museum at Albany as lectotype. It was illustrated by Clark in 1908 on Pl. 12, fig. 3 and again in 1921 on Fig. 84a, p. 99. Photographed at the N. Y. State Museum, it is Figure 7 of our Plate 11.

DISCUSSION: The nature of *Caulostrepsis* was discussed by Clark, and after some deliberation (1907, p. 169) he placed the fossil among the borings ascribed to worms (1921, p. 99). Same opinion was expressed by Newell in regard of our species (1942). However, we conclude that it is more likely the effect of lodging resulting in pseudoboring of a certain animal, possibly worm, on inner side of some shells. (*See* our discussion in the description of *Caulostrepsis dunbari* n. sp.)

Caulostrepsis has a shape unlike any other borings and pseudoborings in the shells of marine in-

vertebrates. Clark (1908, p. 169) describes the shape of its casts as "narrow tape like tongues with an elevated edge all the way around." except, as we may add, the thin narrow tip of the "tongue" which is usually (but not always) directed toward the outer edge of a "host" shell.

DIAGNOSIS: Pseudoborings, commonly appearing as molds, in some thick-shelled brachiopods and pelecypods; tongue-shaped, with swelled edges and flat narrow end directed usually toward the edge of "host" shells.

Caulostrepsis dunbari n. sp.

1942. "Borings of commensal worms." NEWELL, Univ. Kans. Pub., vol. 10, pt. 2, *Mytilacea*, Pl. 8, 4, 5.

HOLOTYPE: Nebraska Geological Survey No. 444. Upon inner surface of outer ostracum (inner ostracum not preserved) of *Myalina* (*Orthomyalina*) *slocomi* in a thin limy seam near base of Doniphan shale member, Lecompton formation, Shawnee group, Pennsylvanian. At Snyderville quarry, 3 miles west, 1 mile north of Nehawka, Nebraska.

DESCRIPTIONS: All known specimens of this species were found in intimate connections with large shells of *Myalina*. In Snyderville quarry locality, where they were repeatedly collected, only the thin outer ostracum of these shells is preserved and because of this, the species was thought to be adnate upon the inner surface of the shells. Actually, they developed entirely within the shell of *Myalina*, in its thick, inner ostracum, which is entirely leached out or replaced by crystalline calcite, the residual parts of which are found occasionally adherent in small patches to the surface of the molds. The thickness of *C. dunbari* molds is well within the restored thickness of these *Myalina* shells, as based on observation of occasionally found completely preserved shells. In another locality, in the Wamego ("Pierson Point") shale formation 2 miles east of Maple Hill, Kansas, *C. dunbari* was found entirely enclosed in a preserved *Myalina* shell, but its presence is revealed from outside because of the mechanical collapse of the thin outer ostracum over the nearly hollow cast of *C. dunbari*)Pl. 9, fig. 8; Pl. 10, fig. 2). When the mold in the shell is filled by matrix before such collapse of the outer ostracum there could be seen no outer indication of its presence in the shell.

Although the orientation of *C. dunbari* in the *Myalina* shell is generally irregular, its most flattened, initial part is invariably located along the lines or slightly diagonally to shinglelike layers of the outer ostracum. The surface of the flattened molds which is usually adnate upon the inner surface of outer ostracum is nearly flat, while the opposite surface, which faces inside the shell and is usually observed, is distinctly sculptured and its margins are more or less distinctly swelled to form a horseshoelike outline, with the opening at the much flattened initial part of the vesicle. The surface inside this horseshoelike swelling is nearly flat, but has faint curved lines, apparently of growth, with curvature directed outward from the initial point.

The molds are variable in size, apparently representing different stages of development. The largest molds observed are 17 mm. long, 9 mm. wide at the widest point, and 2 mm. thick, as measured on the holotype.

Some specimens collected from the Doniphan shale at the Pollard farm quarry located 1½ miles west of Nehawka, Nebraska (Pl. 11, fig. 8) are unlike all other material collected in that the molds are attached to shells in a different manner. They protrude upon the outer and not the inner surface of a *Myalina* shell without breaking through it, but wrapping it around their bodies as if it were tin foil. When we cut, polished, and etched some molds of *C. dunbari* we found it packed with numerous small unidentifiable angular calcareous fragments which are probably remains of food used by the lodged animal, but we found no traces of the animal itself.

DISCUSSION: *Caulostrepsis dunbari* molds on *Myalina* (*Orthomyalina*) *slocomi* from Kansas were recently illustrated by Newell (1942, Pl. 8, figs. 4, 5) and said to be "borings of commensal worms" . . . (p. 96). Newell gives a short discussion on the molds in which he says that the living

"annelid worm, *Polydora ciliata*, commonly infests oysters and mussels, living in burrows drilled into the shell substance of the pelecypod. The worm enters through a hole the size of a pin and makes a U-shaped burrow in the shell . . .;" he concludes that "Paleozoic Mytilacea were infested by similar boring annelids (Pl. 8, figs. 4, 5)."

A letter to Doctor Newell in regard to *Caulostrepsis* with its possible relation to marine worm borings brought the reply: "I have been unable to devote time to a study of these interesting structures. Consequently my notions on the subject would be of little value. You should delve into the literature on these living boring forms."

Dr. Galtsoff of U. S. Bureau of Fisheries cordially supplied us with a list of references on the latest literature on the living annelids infesting oysters and other pelecypods. The literature suggested by Dr. Galtsoff was secured and consulted. In the papers by Whitelegge (1890) and Lunz (1941) the part played by *Polydora ciliata* in causing what is called "mud blisters" in oyster shells, is explained as follows:

"The worm simply swims into the oyster when the valves are open for feeding and then secures a favorable position in the shell. Within a very short time the worm has collected a blob of mud around itself. The oyster immediately begins to secrete the chitin-like layer over this irritating mass and rapidly the mud and the worm are covered over. At a somewhat slower rate the mud and the chitinous layer are covered with nacre. The worm meanwhile has constructed the two canals to the outisde. These canals always have been found present in the mud blisters in which living worms are found. In innumerable cases the canals have all the appearances of being cut or etched into the nacreous layer of the oyster on which the mud blister is formed."

Lancaster (1868) has suggested that "*Polydora* can secrete a powerful acid which would account for the formation of the canals" (Lunz, 1941, p. 275). From this description and the illustrations by Lunz it is clear that *Polydora* does not drill its way into the oyster shell, but it may etch it by acid secretion.

In a recent discussion on Carboniferous *Spirorbis* Trueman (1942) observes that these coiled tubular worms produce deeply marked impressions on the outer surfaces of *Naiadites* and other pelecypods, to which they are often attached. Says Trueman (p. 313) "When the worm tube breaks or falls away it leaves a very sharp and clear mold of its position" and "no evidence has been noticed of *Spirorbis* tubes which could be regarded as being underneath the peristracum of the shell;" he concludes that the sharp impression is produced not by boring or by etching of the worm but rather by the normal growth of the molluscan shell around the surface of attachment which remains stationary.

In our studies of *Spirorbis* from the Pennsylvanian of Nebraska, Oklahoma, and other states we find it occasionally attached to the lateral surface of lophyophyllid corals, to fenestrate Bryozoa, to compressions of terrestrial plants, and rarely, to *Myalina* and other fossils. In all these cases the worm tube is invariably solidly connected with the surface of attachment, and does not fall off. We did not observe scars of attachment left by this fossil worm.

The structure of *C. dunbari* is comparable to the mud-blisters in the modern oyster shell in that both are bilaterally symmetrical (if we discount incidental lateral curvatures) and the U-shaped canals of the blisters may correspond to the horseshoe swelling at the edges of *C. dunbari*. On the other hand the mud-blisters are thickest in the middle and thin out sharply at the edges, while in *C. dunbari* the middle part is flat and somewhat depressed, and the edges are swelled and rounded up. Dunbar (letter of March 3, 1943) believes that the faint concentric lines in the flattened middle part of *C. dunbari* indicate successive position of animal as it grew. This suggestion finds support in the existence of all gradations of sizes among the molds of *C. dunbari*, apparently representing various stages of growth represented by the collected molds.

These stages could represent gradual advances as the animal bored in as Dunbar suggests, or gradual growth of the lodged animal itself, as we think.

Dunbar's discussion is as follows:

"It is evident both from a comparison of specimens of different size and from the 'growth-lines' on the specimen that these structures started as a small lunate cavity. It grew larger by additions on the convex side . . . . The original early stage was apparently a simple tube, widest in the middle and tapering toward the hole at either end. The animal which occupied it was presumably sub-cylindrical. I think it maintained a sub-cylindrical form as the burrow was expanded by excavation on the convex side and possibly filling by matrix on the concave side. The diameter of the tube increased progressively, being largest at the periphery. If this inference is correct, the animal which made that burrow was worm-like in form, whatever phylum it may represent. Certainly there are numerous worms that live in U-shaped burrows which they enlarge progressively in a similar fashion by excavation on the convex side and filling on the concave side. In the Paleozoic sandstones there are such large burrows as *Daedalus*."

TABLE 2.—*Stratigraphic distribution of true and questionable Paleozoic Ctenostomata*

Genera and Species	Geologic Age																					
	Ordovician		Silurian	Devonian			Mississippian				Pennsylvanian							Permian	
	Early	Late		(Early)	(Medial)	(Late)	(Early)	Keokuk	Warsaw	Chester	Pottsville	Cherokee	Marmaton	Missouri	Douglas	Shawnee	Wabaunsee	Big Blue	(Late)
Ascodictyon nebraskensis Condra and Elias																	X	X	
A. oklahomensis Condra and Elias.																	X		
A. northropi Condra and Elias.														X					
A. youngi Vine										X									
A. sparsum Ulrich and Bassler										X									
A. parvulum Ulrich and Bassler										X									
A. stellatum Nicholson and Etheridge, Jr.					X														
A. fusiforme Nicholson and Etheridge, Jr.					X														
A. floreale Ulrich and Bassler					X														
A. filiciforme Vine			X																
A. siluriense Vine			X																
A. radiciforme Vine			X																
Vinella ulrichi Condra and Elias.																X			
V. repens Ulrich			X																
Allonema globiforme Condra and Elias																X			
A. minimum Ulrich and Bassler														X					
A. aggregatum Ulrich and Bassler.					X														
A. moniliforme (Whiteaves)					X														
A. waldronense Ulrich and Bassler.			X																
A. botellus (Vine)			X																
A. botelloides Ulrich and Bassler.			X																
Rhopalonaria permiana Bassler																			X
R. timorensis Bassler																			X
R. dendriformis Condra and Elias.																		X	
R. graphicus Condra and Elias																		X	
R. keokukensis Ulrich and Bassler.									X										
R. tenuis Ulrich and Bassler					X														
R. robusta Ulrich and Bassler					X														
R. (?) *antiqua* (Portlock)			X																
R. attenuata Ulrich and Bassler		X																	
R. venosa Ulrich		X																	
Bascomella fusiformis Condra and Elias																X	X		
B. gigantea Morningstar											X		X	X	X	X	X	X	X

TABLE 2—*Continued*

Genera and Species	Geologic Age																				
	Ordovician		Silurian	Devonian			Mississippian				Pennsylvanian								Permian		
	Early	Late		(Early)	(Medial)	(Late)	(Early)	Keokuk	Warsaw	Chester	Pottsville	Cherokee	Marmaton	Missouri	Douglas	Shawnee	Wabaunsee	Big Blue	(Late)		
Heteronema parvula Condra and Elias													X				X	X			
H. magna Condra and Elias													X	X	X	X	X	X			
H. carbonarium Ulrich and Bassler												X									
H. capillare Ulrich and Bassler			X																		
H. (?) *contextum* Ulrich and Bassler		X																			
PROBLEMATICA																					
Caulostrepsis dunbari Condra and Elias																X	X	X			
C. taeniola Clark				X																	

Dunbar's description of the lectotype of *C. taeniola* and conclusion on the origin of *Caulostrepsis* is as follows (letter of June 23, 1943): The type is

"a mold of the interior side of a dorsal valve of a *Stropheodonta* from the Coblentzian (Lower Devonian) of Seifen, Germany. . . . The dorsal valve was relatively flat over the central portion and then curved up very sharply toward the margins."

"As shown by Clark's figure, the loops are somewhat radially disposed and are largely confined to the upcurved margins of the shell, and in general the apertures are distally directed. It is evident that the boring organism entered from the outside of the shell, somewhat near the margin, after the brachiopod was almost fully grown. The orientation may have been due to a tendency of the boring organism to work downwards, since the front and anterolateral margins of the brachiopod shell were curved strongly upward, as indicated in the diagram."

"In places the loops have peeled away from the mold, showing that there was originally a film of shell between them and the outside of the brachiopod. In three or four places, one loop overlaps another but they do not intercept one another. Evidently the brachiopod shell was originally thick enough to accommodate two layers of the boring organisms."

"Some of the loops on the right side show in the photograph what is much more clearly shown in the specimen, namely, varices of growth like those in our Nebraska specimens, indicating that the loops have been successively extended, expanding and changing shape gradually as they did so."

"The structure of these burrows appears to be identical with ours in all essential features. In specific characters they are obviously different, the loops in the Devonian shell being relatively narrow and slender and having the elevated rim, which undoubtedly represents the final burrow, thinner and more slender than it is in our specimens."

The maximum width of *C. taeniola* molds is 4.5 mm. and the length up to 16 mm. *C. dunbari* molds have same length, but their width is twice as large, up to 9 mm.

We do not think that the animal bored its way in shell because the individual molds of *C. dunbari*, as well as of *C. taeniola* are never inter-connected, which would happen occasionally between neighboring structures if they were molds of excavated tunnels. The boring excavations in the living shells are invariably interconnected. Furthermore the excavations need not be as identical in pattern as are the molds of *Caulostrepsis*. Clark correctly pointed out that in "host-shells" which have been well "riddled" by various tubes and channels "closely crowded together in numbers, there is very rarely any evidence that one crosses another or even touches its neighbors." Dunbar also observes this in the lectotype of *C. taeniola* and this is also the case with *C. dunbari*. This fact can be reasonably

understood if the neighboring animals were sharing the surface of same shell, each having own area of feeding, but not if they were boring blindly within the same shell. The presence of "two layers of the boring organisms" in *C. taeniola* may indicate as well that after the growth of the earlier group of *C. taeniola* was completed and covered by the shell growth of *Stropheodonta*, more animals swam in and started to develop a new layer of pseudoborings.

The following suggestion regarding mode of life of the animal that produced *Caulostrepis* seems to be compatible with all known facts and observations as just described. The animal probably swam in and lodged near the edge of the inner side of shells when young and small. As the "host" shell continued to grow, so did also the lodged animal, which continued to have an outlet from the host-shell through outer ostracum at the point of the original lodging. As the lodged animal grew it was etched into the older layers of the inner shell substance, as it is clear that it was spreading its contact along or near the inner surface of the outer ostracum of the shell, usually towards its apex, that is towards its older part. If neighboring lodged animals grew so close together as to compete for common food supply, the most successful of the neighbors would deprive the others of part of food and cause deviation in the direction of their growth away from the successful competitor, or (and) would cause partial or complete check of their growth. Thus their scars of attachment would remain separated, as observed in *Caulostrepsis*.

If the lodged animal derived important part or all of its food from the "host" parasitically, or using products of its metabolism, or sharing the food which the host managed to get, then the end of life of the latter would result in the death of the former. In the post-mortem processes the space occupied by the lodging animal usually became solidified through impregnation of lime, while the inner ostracum of the "host" shell was subsequently destroyed, probably because being composed of aragonite. The hardened molds of the lodging spaces are occasionally subsequently pressed into the preserved thin outer ostracum of the *Myalina* shells (Pl. 11, fig. 8), an explanation suggested by Dunbar (letter of March 12, 1943). In rare instances the lodging space has not been solidified, and it is the outer ostracum which under pressure is broken over it and caves in (Pl. 9, fig. 8).

What is the animal that lodged and etched its way as it grew on the inner side of a "host" shell—we do not know. It is very likely a marine worm, as Dunbar suggests. The habit of the living *Polydora ciliata* to swim in and cause "blisters" in the modern oyster shells is suggestive of somewhat similar habit for some paleozoic worms, and the difference in structure of the corresponding "blisters" or lodging spaces may be ascribed to the differences in the host shell and in the worms themselves or both. The fact is, however, that the effect of lodging of apparently same kind of animal in the shell of the Devonian brachiopod *Stropheodonta* from Germany, and in the shell of the Pennsylvanian pelecypod *Myalina* from Nebraska and Kansas, results in structures of very similar nature, and these structures are not very like that of the blisters in the living oyster. Consequently, we place *Caulostrepsis* among fossils with problematic affinity.

OCCURRENCES:

(1) On inner surface of outer ostracum (inner ostracum not preserved) of *Myalina* (*Orthomyalina*) *slocomi*. Doniphan shale member, Lecompton formation, Shawnee group, Pennsylvanian. At Snyderville quarry, 3 miles west, and 1 mile north of Nehawka, Nebraska.

(2) Within the shell of *Myalina* (*Orthomyalina*) *slocomi*. Visible because of the impression of the outline of the vesicles on the pushed out outer ostracum. Doniphan shale member, Shawnee group, Pennsylvanian. Pollard farm, 1 mile west of Nehawka, Nebraska.

(3) Within the shell of *Myalina* (*Orthomyalina*) *subquadrata*, visible on them because of collapse over the vesicles of the outer ostracum. Base of Wamego shale formation, Wabaunsee group Pennsylvanian. In RR cut about 2 miles east of Maple Hill, Wabaunsee County, Kansas.

(4) On inner surface of outer ostracum of *Myalina subquadrata*. Aspinwall limestone, Admire group, Permian. RR cut 3 miles east of Foraker, Oklahoma.

Also observed in *Myalina* in illustrations by Newell (1941), as follows:

(5) In the left valve of *M. slocomi*. Upper Stull shale (upper part of Kanwaka shale formation), Shawnee group, Pennsylvanian. About 5 miles east, 2¼ miles north of Strawn, Coffey County, Kansas.

(6) In the left valve of *M. slocomi*. Ozawkie limestone member, Deer Creek formation, Shawnee group, Pennsylvanian. 1 mile south of Lyndon, Osage County, Kansas.

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——— (1895) *On lower Silurian Bryozoa of Minnesota*, Minn. Geol. Nat. Hist. Survey, Geology of Minnesota, vol. 3, part 1, p. 96–332, 20 figs.

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Nebraska Geological Survey, University of Nebraska, Lincoln, Nebraska.
Manuscript Received by the Secretary of the Society, February 3, 1943.
Project Grant 35 5/40.

EXPLANATION OF PLATES

PLATE 1.—*ASCODICTYON* AND COMPARABLE LIVING BRYOZOA

Figure

(1–2) Living cheilostomatous Bryozoa having adnate stolons.

(1) *Aetea anguina* Linnaeus (= *Anguinaria spatulata*). After Busk, 1852, Pl. XV, fig. 1. Showing fusiform differentiation and perforation of the adnate stolons, from which zooecia arise. × abt. 40.

(2) *Aetea ligulata*. After Busk, 1852, Pl. XLII. Showing irregular fusiform differentiation of the perforated adnate stolons. × abt. 40

(3–6) Living ctenostomatous Bryozoa having adnate stolons.

(3–5) *Farella atlantica*. After Busk, 1886. Showing adnate stolons, stellar arrangement of baglike undeveloped zooecia and stages in development of zooecia. Figs. 3, 4, × 50. Fig. 5, × 110.

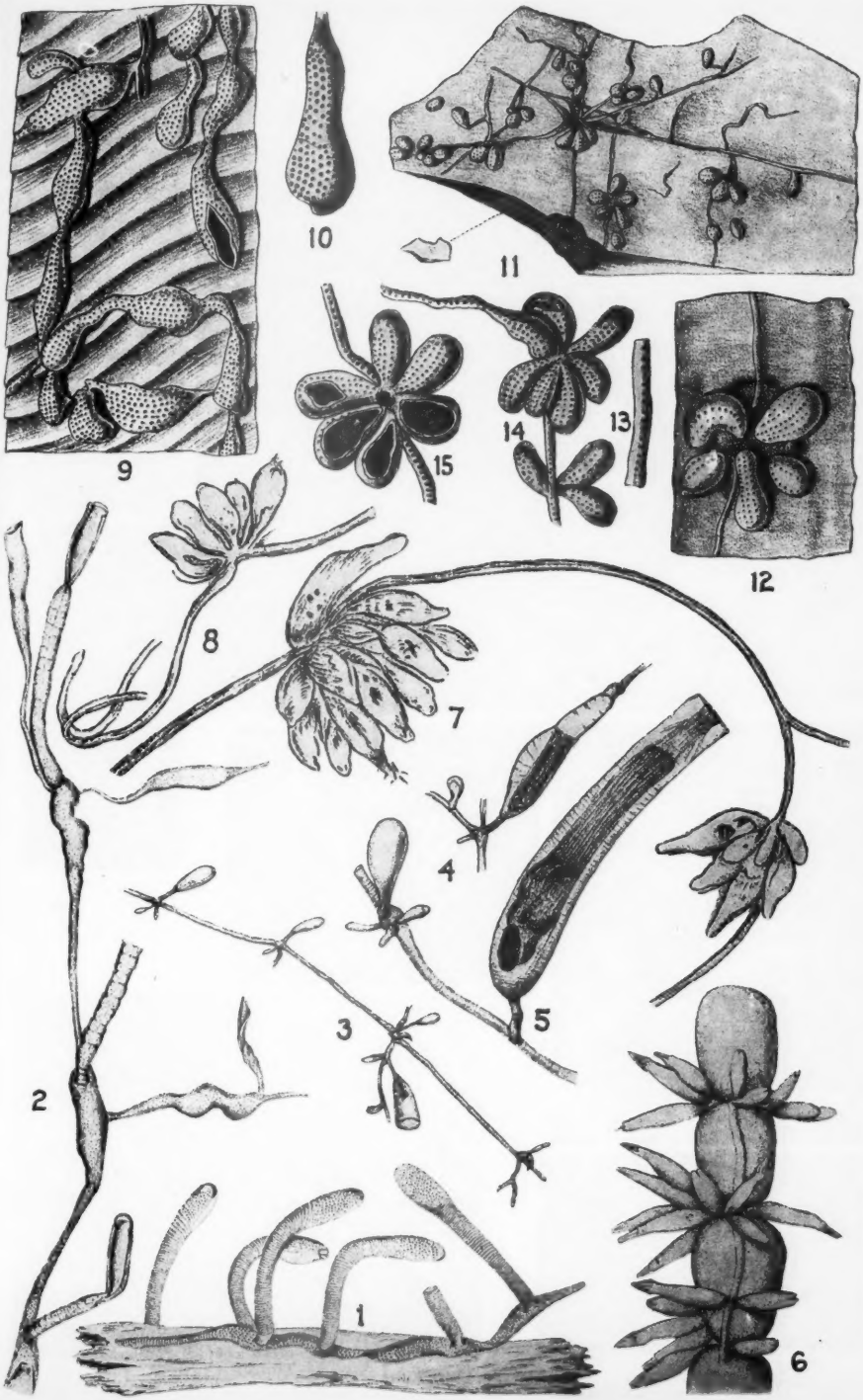
(6) *Valkeria uva* Linnaeus. "Repent form" on an alga (a) (*Corallina*). After Hinks, 1880, Pl. 75, fig. 5. Showing adnate stolons (b) and grouping of undeveloped (c) and developed (d) zooecia. × abt. 25.

(7–8) *Valkeria tuberosa* Keller. After Vine, 1895, Pl. IV, figs. 2, 2a. Showing whorls of zooecia at various stages of development, on delicate hollow stolons. × abt. 25.

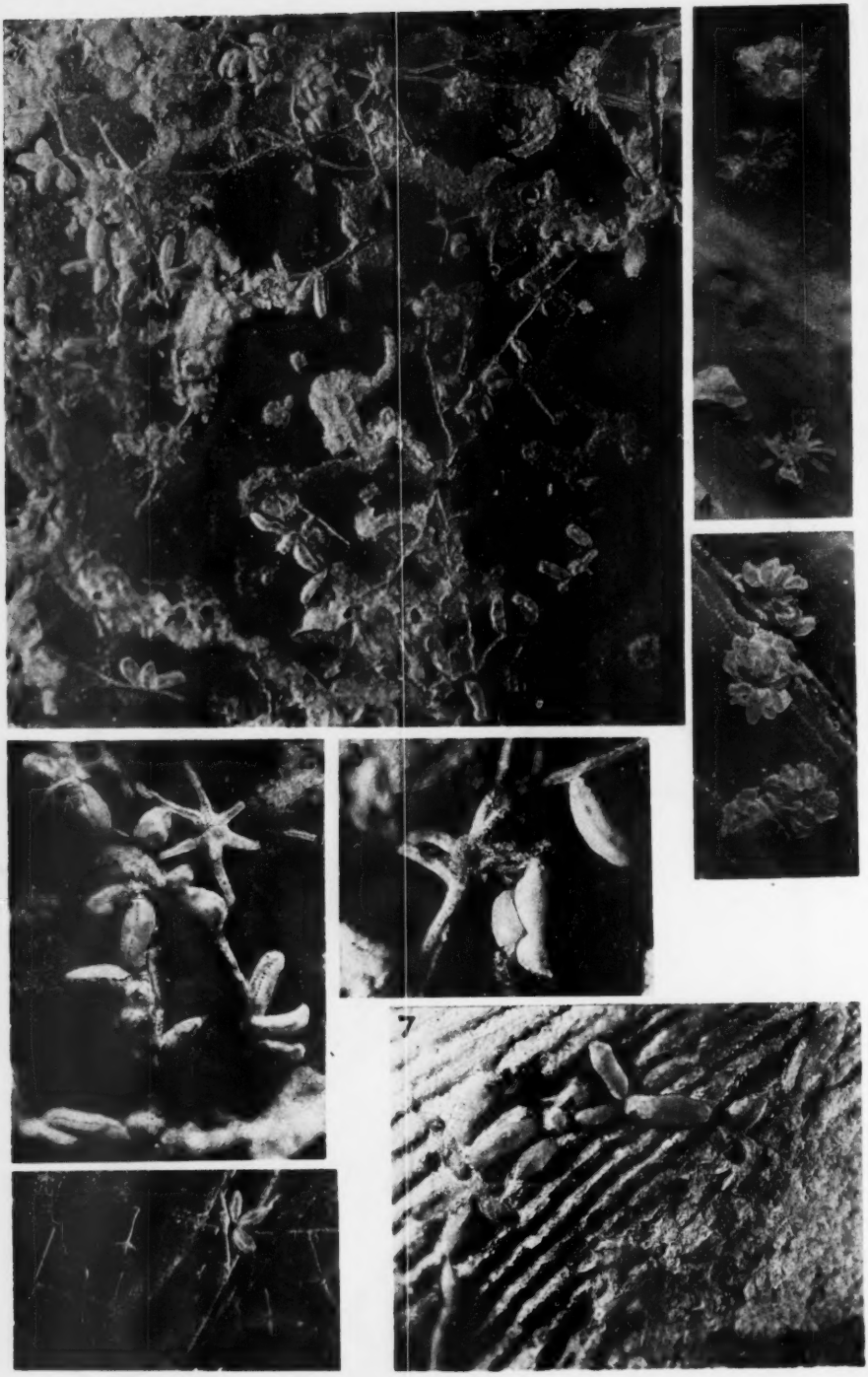
(9–15) Fossil ctenostomatous Bryozoa.

(9–10) *Ascodictyon fusiforme*. After Nicholson and Etheridge, Jr. 1877, Pl. 19, figs. 7, 8. On *Spirifer mucronata*, Hamilton formation (Middle Devonian) at Widder, Ontario. Fig. 9, × 15. Fig. 10, × 30.

(11–15) *Ascodictyon stellatum*. After Nicholson and Etheridge, Jr., 1877, Pl. 19, figs. 1-5. On the hinge area of *Cyrtina hamiltonensis*, Hamilton formation (Middle Devonian), at Widder, Ontario. Fig. 11 × 10. Fig. 12 × 20. Fig. 13 abt. × 50. Fig. 14 × 25, Fig. 15 × 30.



ASCODICTYON AND COMPARABLE LIVING BRYOZOA



ASCODICTYON

PLATE 2.—*ASCODICTYON*

Figure

(1–6) *Ascodictyon nebraskensis* n. sp.

(1–3) Holotype. Nebr. G. S. No. 401. On inner side of *Myalina* (*Otrhomyalina*) *slocomi*. Hughes Creek shale, Big Blue series, Permian. 1 mi. southeast of Bennett, Nebraska. Fig. 1, × 20, figs. 2–3, × 40.

(4–5) Nebr. G. S. No. 402. On outer side of *Myalina* (*Ortomyalina*) *slocomi*. Same locality as figs. 1–3, × 20.

(6) Nebr. G. S. No. 403. On inner side of *Myalina* (*Orthomyalina*) *slocomi*. Palmyra limestone Wabaunsee group Pennsylvania. 7 mi. south, 1 mi. west of Pawnee City Nebraska. × 20.

(7) *Ascodictyon fusiforme* Nicholson and Etheridge, Jr. U. S. Nat. Museum No. 89311. On outer side of ventral valve of *Chonetes coronatus*, Silica shale, Traverse formation, Devonian. 2½ mi. southwest of Sylvania, Ohio, × 20.

PLATE 3.—*ASCODICTYON* AND LIVING *CHLIDONIA*

Figure

(1–4) *Ascodictyon northropi* n. sp.

(1, 2) Holotype, Nebr. G. S. No. 412. On *Spirifer opimus*, from Magdalena limestone, Pennsylvanian. From near Santa Fe, New Mexico. Fig. 1, × 2; fig. 2, × 20.

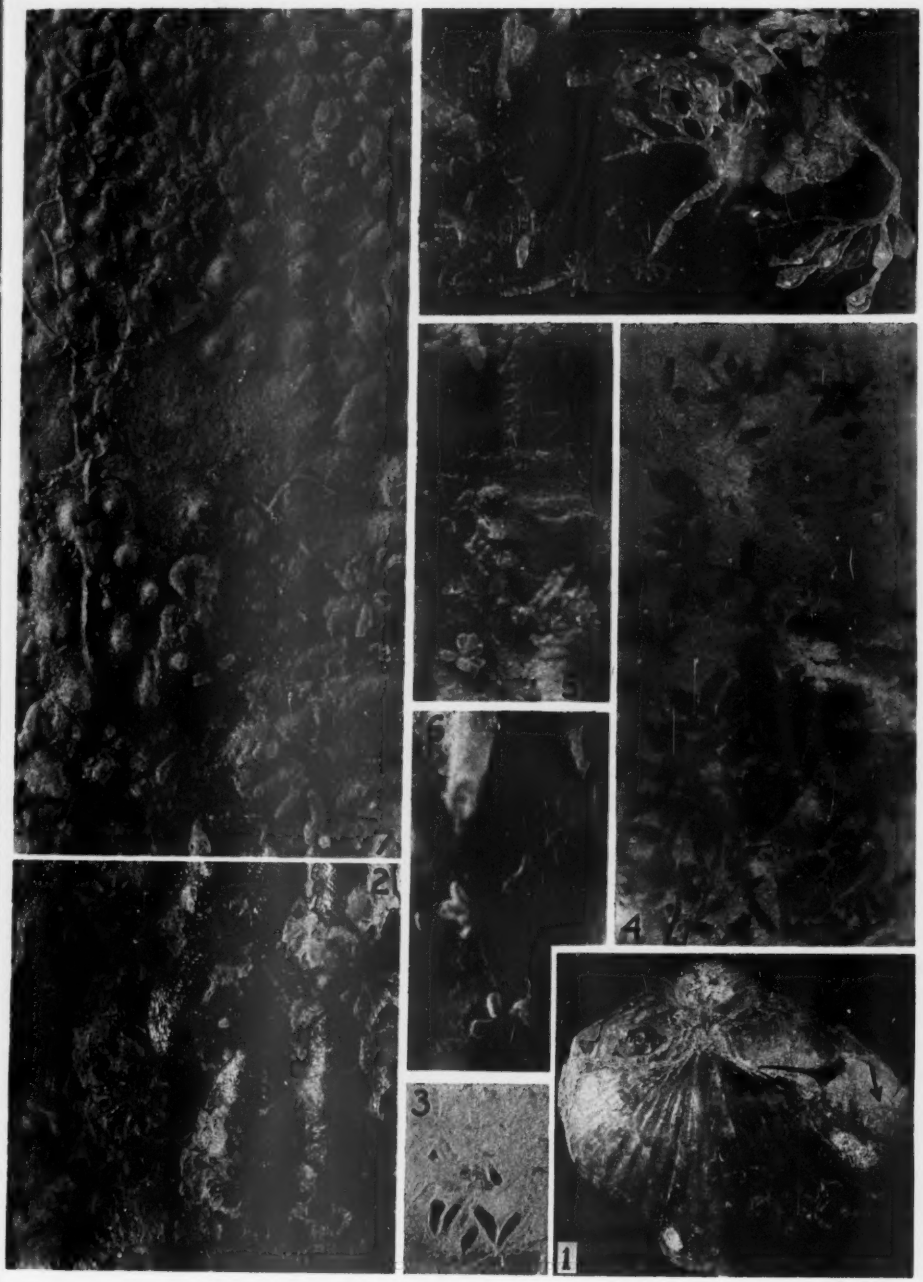
(3, 4) Nebr. G. S. No. 413. On *Myalina* (*Orthomyalina*) *slocomi* Sayre from middle part of Drum limestone Missouri series. At water works at North Kansas City, Missouri. Figs. 3 and 4 view of the flat basal part of the stoloniferous colony as it cracked off with the embedding matrix from the inner surface of the shell, × 20. Fig. 5 thin section of the basal part, showing the thickness of the wall of vesicles, × 20.

(5–7) *Ascodictyon nebraskensis* n. sp.

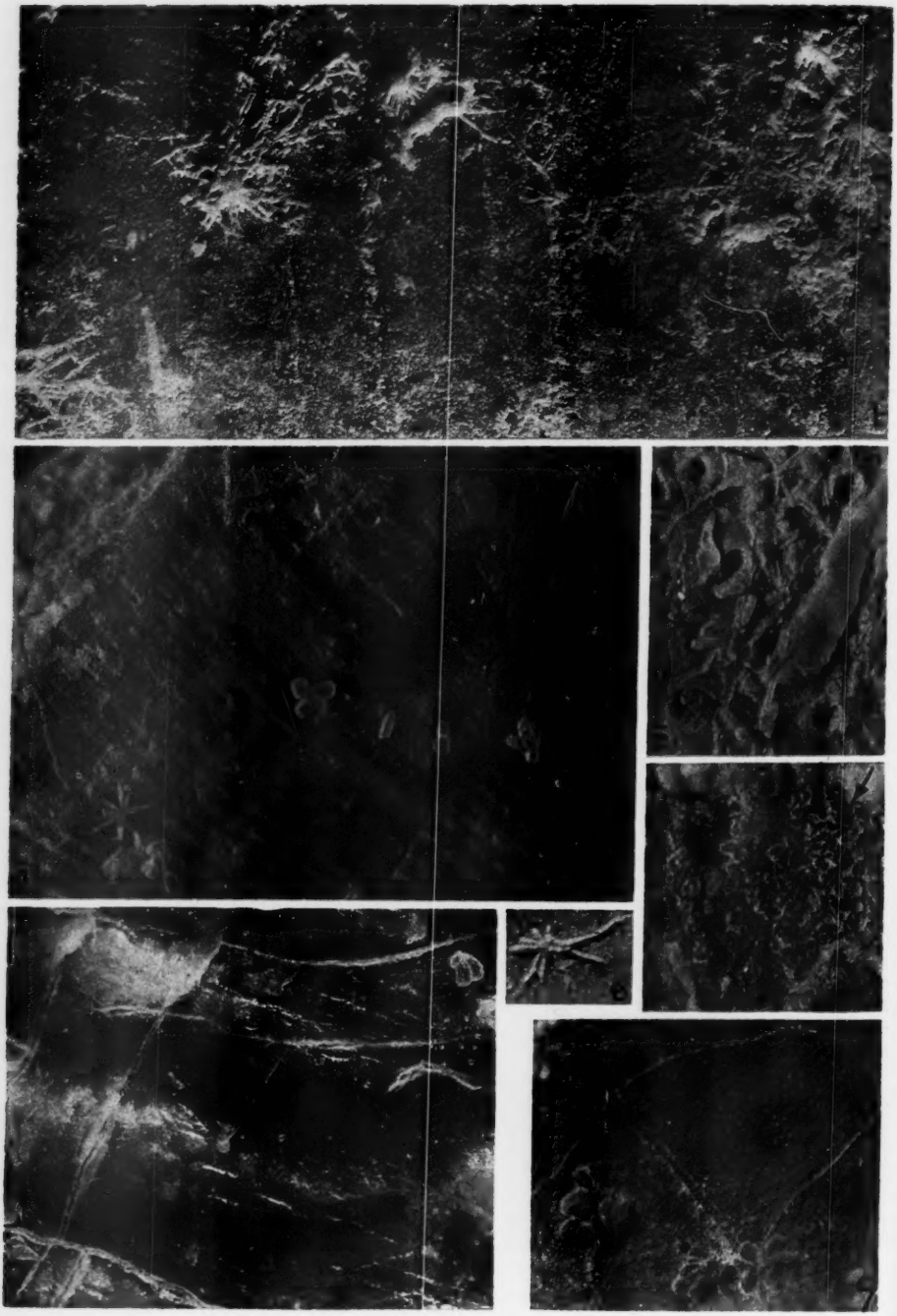
(5 6) Nebr. G. S. No. 411. On *Juresania nebraskense*, Langdon shale, Wabaunsee group, Pennsylvanian. Near Aspinwall Ferry, southeast of Nemaha City, Nebraska. × 20.

(7) Nebr. G. S. No. 407. On outer side of dorsal valve of *Chonetes granulifer*. Hughes Creek shale Big Blue series Permian. 3 mi. south of Stine Nebraska. × 20.

(8) *Chlidonia cordieri* (Audouin), attached to alga, *Phyllopora nervosa*. From near Marseille, France. University of Nebraska Herbarium No. 207007. × 20. Illustrated for comparison with the fossil *Ascodictyon*. Identification of *Chlidonia* by Doctor Louis W. Hutchins, Ohio State University.



ASCODICTYON AND LIVING *CHLIDONIA*



ASCODICTYON

PLATE 4.—*ASCODICTYON*

Figure

(1) *Ascodictyon* (?) *oklahomensis* n. sp. Nebr. G. S. No. 414. On crinoid stem. Upper part Wabaunsee group, Pennsylvanian. RR cut 2½ miles east of Foraker, Oklahoma.

(2–7) *Ascodictyon nebraskensis* n. sp.

(2) Nebr. G. S. No. 409. On *Chonetes granulifer*, from Hughes Creek shale, Big Blue Series, Permian. 3 miles south of Stine, Nebraska.

(3) Nebr. G. S. No. 410. On *Juresania nebraskense*, from Sallyards limestone, Grenola formation, Big Blue series, Permian. Near Pawnee, Oklahoma.

(4) Nebr. G. S. No. 408. On outer side of dorsal valve of *Chonetes granulifer*. Hughes Creek shale, Big Blue series, Permian. 3 mi. south of Stine, Nebraska.

(5) Nebr. G. S. No. 406. On *Meekopora prosseri*. Hughes Creek shale, Big Blue series, Permian. 1½ mi. west of Glenrock, Nebraska.

(6, 7) Nebr. G. S. No. 404 and 405. On inner side of *Myalina* (*Orthomyalina*) *slocomi*. Hughes Creek shale, Big Blue series, Permian. 1 mi. southeast of Bennett, Nebraska.

(All figures × 20)

PLATE 5.—*ASCODICTYON*

Figure

(1–6) *Ascodictyon radiciforme* Vine. Buildwas beds of Wenlock shales, Silurian. Shropshire, England. After Vine, 1884, p. 83, figs. 1-5 (magnification high, but not indicated).

(7–8) *Ascodictyon stellatum* Nicholson and Etheridge, Jr. Hamilton formation, Devonian. Eighteen Mile creek, New York. After Ulrich, 1893, fig. 8a (p. 113) and Ulrich and Bassler, 1904, Pl. LXVIII, fig. 10. Fig. 7, × 20; Fig. 8, × 10.

(9–10) *Ascodictyon* (?) *conferta* (Ulrich). Waldron shale, Silurian. Waldron, Indiana. After Ulrich, 1893, figs. 8c, d, p. 113. Fig. 7, ×5; Fig. 8, × 20 (enlarged from original magnifications × 4.5 and × 18).

(11–13) *Ascodictyon radians*, Nicholson and Etheridge, Jr. Lower Carboniferous. Scotland. After Nicholson and Etheridge, Jr., 1877, Pl. 19, figs. 9-11. Fig. 9, × 1; Fig. 10, × 30; Fig. 11, × 60.

(14) *Ascodictyon fusiforme*. On poriferous side of a small *Polypora*. Hamilton formation, Middle Devonian. Alpena, Michigan. After Ulrich and Bassler, 1904, Pl. LXVII, fig. 8, × 10 (enlarged from original magnification, × 9).

(15) *Ascodictyon* (?) *radialis* (Ulrich). On *Orthoceras*, Corryville member, McMillan formation, Lorraine group, Upper Ordovician. At Cincinnati, Ohio. After Ulrich, 1893. Fig. 8b, × abt. 1.

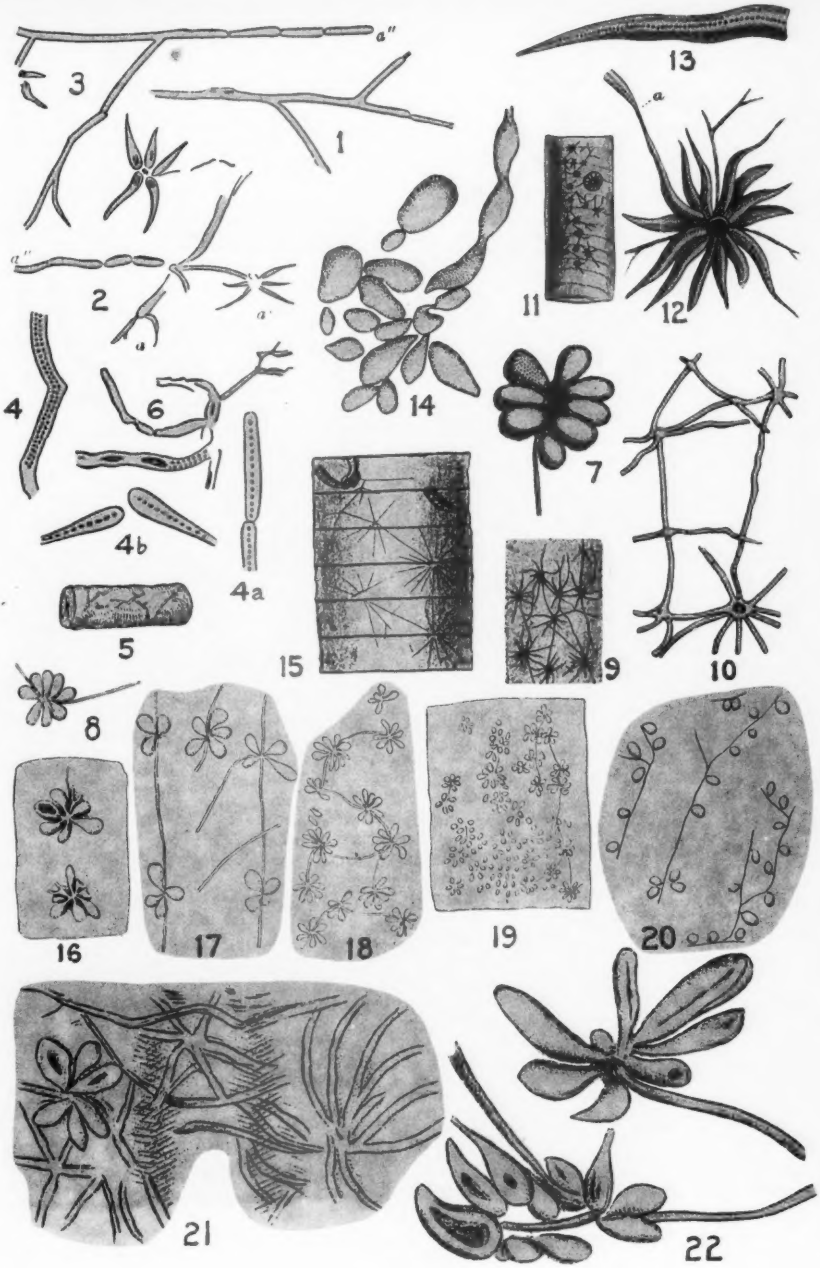
(16–17) *Ascodictyon siluriense* Vine.
(16) On *Leptaena rhomboidalis*. Rochester shale, Silurian, Lockport, New York. × 10
(17) On small *Orthoceras*. Waldron shales, Silurian. Waldron, Indiana. × 10.

(18) *Ascodictyon floreale* Ulrich and Bassler. On *Stropheodonta*. Hamilton formation, Devonian. 2 mi. west of Alpena, Michigan, × 10.

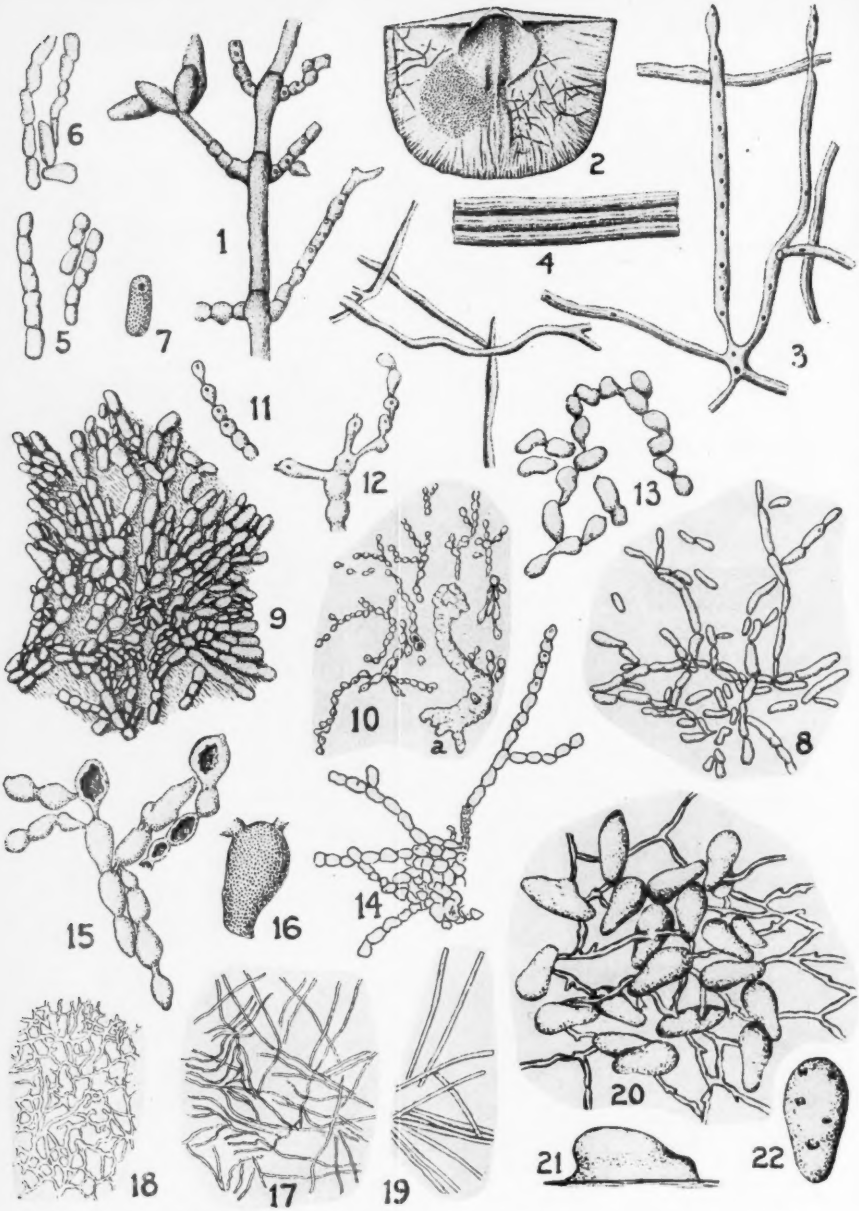
(19) *Ascodictyon parvulum* Ulrich and Bassler, on a crinoid stem. Chester group, Mississippian, Jackson County, Kentucky. × 10.

(20) *Ascodictyon sparsum* Ulrich and Bassler. Chester group, Mississippian. Claxton, Caldwell County, Kentucky. × 10.

(21–22) *Ascodictyon youngi* Vine. Adnate on a crinoid stem (*Platycrinus* sp.). Lower Carboniferous shale. Hairmyres, Scotland. After Vine, 1892, Pl. 4, figs. 3, 4. × abt. 25.



ASCODICTYON



VINELLA, ALLONEMA, BASCOMELLA, HETERONEMA, AND LIVING *VALKERIA*

PLATE 6.—*VINELLA, ALLONEMA, BASCOMELLA, HETERONEMA,* AND LIVING *VALKERIA*

Figure

(1) Living *Valkeria uva* Linnaeus. Erect form. After Hincks, 1889, Pl. 75, fig. 2. Showing differentiation of branches, which are homologous to stolons, by constrictions. × abt. 26.

(2–22) Fossil ctenostomatous Bryozoa.

(2–4) *Vinella repens* Ulrich. On the inner side of a ventral valve of *Strophomena septata*. Black River shale, Trenton, Silurian, St. Paul, Minnesota. After Ulrich, 1893, Pl. 1, figs. 1-3, Fig. 1, × abt. 1. Figs. 2-3, × 20 (enlarged from original × 18).

(5–7) *Allonema botelloides*. After Ulrich and Bassler, 1904, Pl. LXVII, figs. 2-4. On *Goniophyllum pyramidatum* (5) and on a cyathophyllid coral (6, 7), Silurian, Island of Gotland. Figs. 5, 6, × 10, Fig. 7, × 20.

(8) *Allonema botellus*. After Ulrich and Bassler, 1904, Pl. LXVII, fig. 1. On the dorsal valve of *Leptaena rhomboidalis*, Silurian, Island of Gotland, × 10.

(9) *Allonema moniliforme* var. *aggregatum*. After Ulrich and Bassler, 1904, Pl. LXVII, fig. 9. On *Diphyphyllum*, Hamilton formation. (Middle Devonian), Genesee County, New York. × 10.

(10–12) *Allonema minimum*. After Ulrich and Bassler, 1904, Pl. LXVII, figs. 10-12. "Upper Coal Measures," Springfield, Illinois, Fig. 10, × 10. Figs. 11, 12, × 20.

(13) *Allonema* (?) *waldronense*. After Ulrich and Bassler, 1904, Pl. LXVII, fig. 5. On the dorsal valve of an orthoid, Waldron shale, Silurian. Waldron, Indiana. × 10.

(14) *Allonema moniliforme* (Whiteaves). After Whiteaves, 1891, Pl. 28, fig. 10 (from Ulrich and Bassler, 1904, Pl. LXV, fig. 14). Devonian. Hay River, Canada, × abt. 7.

(15–16) *Allonema* (?) *subfusiforme*. After Ulrich and Bassler, 1904, Pl. LXVII, figs. 6, 7. On *Goniophyllum pyramidatum*, Silurian, Island of Gotland. Fig. 15, × 10. Fig. 16, × 20.

(17) *Heteronema capillare*. After Ulrich and Basseler, 1904, Pl. LXV, fig. 11. On a strophomenid shell, Silurian, Island of Gotland, × 10.

(18) *Heteronema* (?) *contextum*. After Ulrich and Bassler, 1904, Pl. LXV, fig. 12. On the celluliferous side of a monticuliporoid bryozoan, Corryville member, Lorraine group, Upper Ordovician. Morrow, Ohio. × 10.

(19) *Heteronema carbonarium*. After Ulrich and Bassler, 1904, Pl. LXV, fig. 13. On a *Spirifer* sp., "Lower Coal Measures." Seville, Illinois. × 10.

(20–22) *Bascomella gigantea*. After Morningstar, 1922, Pl. VI, figs. 18–20. In the cast of a ventral valve of *Spirifer boonensis*, McArthur limestone, Pottsville series, Pennsylvania. Monroe Furnace, Jackson County, Ohio. Fig. 20, × 5; Figs. 21, 22, × 10.

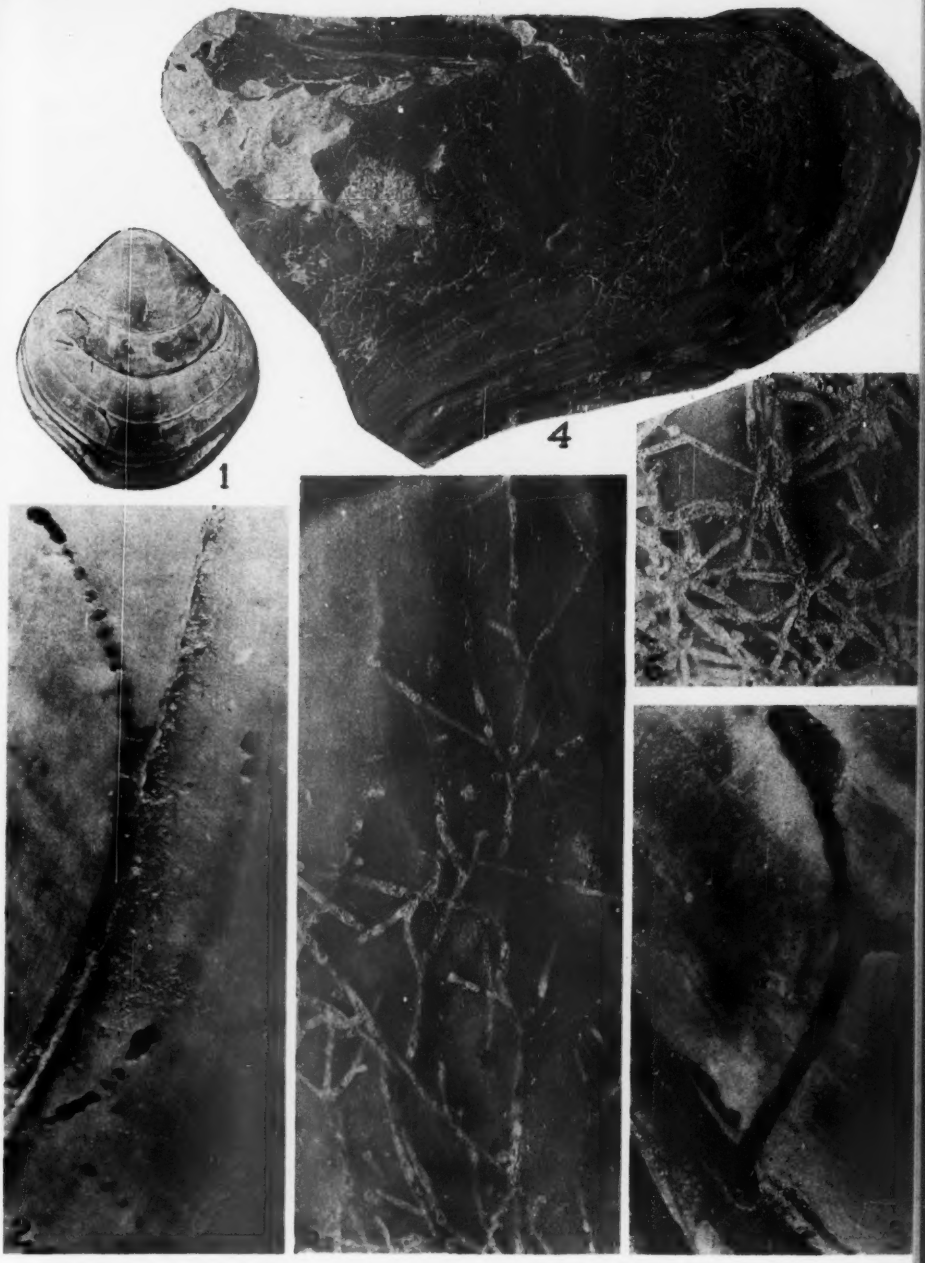
All figures reproduced from Ulrich and Bassler, 1904, enlarged from original magnifications from × 9, × 18, and × 6⅔ to 10, 20, and 7 respectively. Figures reproduced from Morningstar, 1922, enlarged from original magnification from × 4 and × 8 to × 5 and × 10, respectively.

PLATE 7.—*VINELLA* AND *HETERONEMA*

Figure

(1–3) ***Vinella ulrichi*** n. sp. Holotype Nebr. G. S. No. 422. In *Composita subtilita*. Jacksboro limestone, Cisco group, Pennsylvanian. Southeast of Jacksboro, Texas. Collected by Ch. Schuchert. Fig. 1, × 2; Figs. 2, 3, × 20.

(4–6) ***Heteronema magna***, n. sp. Holotype, Nebr. G. S. No. 423. Immersed in outer ostracum of *Myalina* (*Orthomyalina*) *subquadrata*. Kinney limestone, Big Blue series, Permian. About 3 miles east of Barneston, Nebraska. Fig. 1, × 2; Figs. 2, 3, × 10.



VINELLA AND *HETERONEMA*

ALLONEMA AND *HETERONEMA*

PLATE 8.—*ALLONEMA* AND *HETERONEMA*

Figure

(1–3) *Allonema globiforme* n. sp. on *Caninia torquia*. Nebr. G. S. Nos. 415 (Holotype), 416, and 417. Beil limestone, Shawnee group, Virgil series, Pennsylvanian. Snyderville quarry 3 mi. west, 1 mi. north of Nehawka, Nebraska. × 20.

(4) *Allonema aggregatum* Ulrich and Bassler and *Hederella alpensis* Bassler (in lower right corner) on *Stropheodonta hemispherica*. U. S. Nat. Musum No. 97249. Middle Devonian. Alpena quarry, Alpena, Michigan. × 10.

(5–8) *Heteronema parvula* n. sp.

(5–6) Nebr. G. S. No. 428. On a small lophophyllid coral and on *Cladochonus*. Lenapah formation, Marmaton group, Des Moines series, Pennsylvanian. 100 yards north of road, ¼ mi. west of SE cor. sec. 24, T. 26 N., R. 15 E., near Nowata, Oklahoma. Fig. 5, × 2; fig. 6, × 20.

(7) Nebr. G. S. No. 427. On inner side of *Myalina* (*Orthomyalina*) *slocomi*. Base of Kanwaka shale, Shawnee group, Pennsylvanian. Amazonia, Kansas. × 20.

(8) Nebr. G. S. No. 426. Holotype. On inner side of *Myalina* (*Orthomyalina*) *slocomi*. Hughes Creek shale, Big Blue series, Permian. ½ mi. east of Bennett, Nebraska. × 20.

PLATE 9.—*RHOPALONARIA*, *BASCOMELLA*, AND *CAULOSTREPSIS*

Figure

(1) ***Rhopalonaria permiana*** Bassler.

(2) ***Rhopalonaria timorensis*** Bassler.

Figs. 1 and 2 from the Permian of Timor, after Bassler, 1929, Pl. II (CCXXXV), Figs. 1 and 3, × 9.

(3–5) ***Bascomella gigantea*** Morningstar.

(3–4) Holotype and paratype. Ohio State Univ. Geol. Mus. Nos. 19346 and 19345. In casts of *Spirifer opimus*. McArthur limestone, Pottsville series, Pennsylvanian. Monroe Furnace, Jackson County, Ohio. × 10.

(5) Casts in *Stenopora carbonaria*. Nebr. G. S. No. 424. Top of Cass limestone, Douglas group, Pennsylvanian. Burlington quarry, northwest of South Bend, Nebraska. × 2.

(6) ***Caulostrepsis dunbari***, n. sp. Holotype, Nebr. G. S. No. 444. On inner side of outer ostracum of *Myalina* (*Orthomyalina*) *slocomi*. Doniphan shale, Lecompton formation, Shawnee group, Pennsylvanian. Snyderville quarry, 3 mi. west and 1 mi. north of Nehawka, Nebraska. × 2.

(7–8) ***Caulostrepsis dunbari***, n. sp. and ***Bascomella gigantea*** Morningstar.

(7) Nebr. G. S. No. 419. On inner side of outer ostracum of *Myalina* (*Orthomyalina*) *slocomi*. Doniphan shale, Lecompton formation, Shawnee group, Pennsylvanian. Snyderville quarry, 3 mi. west and 1 mi. north of Nehawka, Nebraska. × 2.

(8) Nebr. G. S. No. 425. *Caulostrepsis* in inner ostracum with outer ostracum collapsed over it and *Bascomella* in outer ostracum and partly in inner ostracum of *Myalina* (*Orthomyalina*) *subquadrata* Shumard. Wamego shale, Wabaunsee group, Pennsylvanian. East of Maple Hill, Wabaunsee County, Kansas. × 1.

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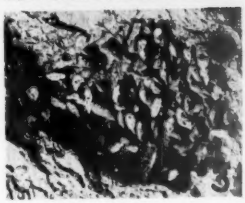

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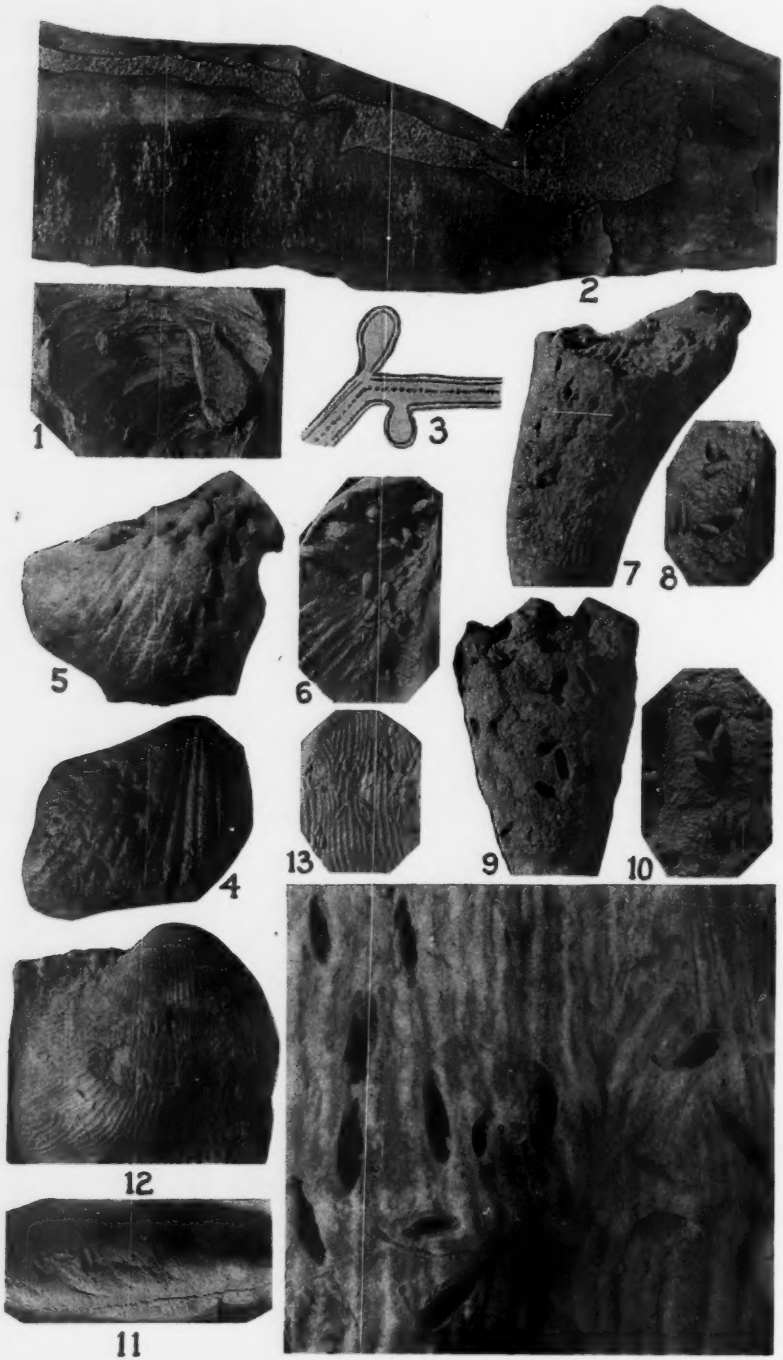
RHOPALONARIA, BASCOMELLA, AND *CAULOSTREPSIS*



BASCOMELLA, ASCODICTYON, AND *CAULOSTREPSIS*

PLATE 10.—*BASCOMELLA, ASCODICTYON,* AND *CAULOSTREPIS*

Figure

(1–2) *Caulostrepsis d··nbari*, n. sp.

(1) Holotype, Nebr. G. S. No. 444. Same specimen as illustrated on Pl. 9, fig. 6. × 1.

(2) Nebr. G. S. No. 425. Same specimen as illustrated on Pl. 9, fig. 8. Polished and etched cut across *Myalina* shell and mold of *Caulostrepsis* in it. Outer ostracum on top, collapsed over *Caulostrepsis* mold. × 20.

(3) *Ascodictyon filiforme* Vine. Buildwas beds, Wenlock shale, Silurian. Shropshire, England. After Vine, 1895, Pl. III, fig. 15, (magnification high, but not indicated). Showing pear-shaped outline of the vesicles, comparable to that of *Caulostrepsis*, and the broad base by which they are attached to the stolon.

(4–11) *Bascomella gigantea* Morningstar.

(4) Squeeze or replica prepared from a paratype, in shell of *Spirifer opimus*. McArthur limestone, Pottsville series, Pennsylvanian. Monroe Furnace, Jackson County, Ohio; × 2.

(5, 6) Nebr. G. S. No. 445. Ventral valve of *Neospirifer cameratus* with casts of *Bascomella gigantea*, and squeeze prepared from same. Cass limestone, Douglas group, Pennsylvanian. Burlington railroad quarry, about $1\frac{3}{4}$ miles northwest of South Bend, Nebraska. × 2.

(7–10) Nebr. G. S. Nos. 446, 447. Lophophyllid coral with casts of *Bascomella gigantea*, and squeezes prepared from same. Winterset limestone, Missouri series, Pennsylvanian, west of Tulsa, Oklahoma; × 2.

(11) Squeeze or replica from near the apex of *Myalina* illustrated on Figure 8 of Plate 9. × 2.

(12–14) *Bascomella fusiformis* n. sp. Holotype, Nebr. G. S. No. 448. Casts of vesicles and squeeze from same, and stolons immersed in ventral valve of *Linoproductus prattenianus*. Cass limestone, Douglas group, Pennsylvanian. Southeast of Ashland, Nebraska. Figs. 12 and 13, × 2; Fig. 14, × 10.

PLATE 11.—*BASCOMELLA* AND *CAULOSTREPSIS*

Figure

(1–6) *Bascomella gigantea* on inner side of outer ostracum of *Myalina* (*Orthomyalina*) *slocomi* Sayre.

(1, 2) Nebr. G. S. Nos. 418, 420. Doniphan shale member, Lecompton formation, Pennsylvanian. Snyderville quarry, 3 mi. west and 1 mi. north of Nehawka, Nebraska. × 10

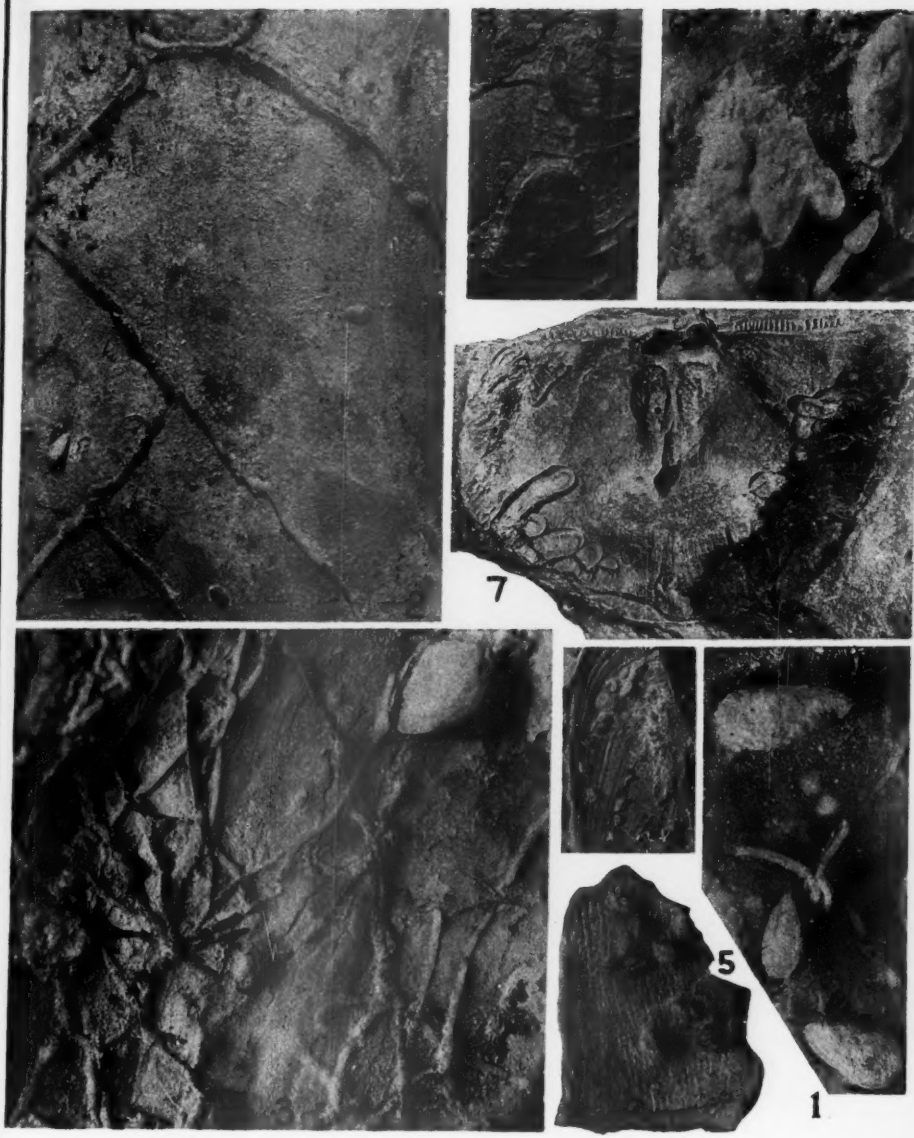
(3, 4) Nebr. G. S. No. 429 and 438. Doniphan shale member, Lecompton formation, Shawnee group, Pennsylvanian. Snyderville quarry, 3 mi. west, 1 mi. north of Nehawka Nebraska. Fig. 3, × 10; fig. 4 × 2.

(5) Nebr. G. S. No. 440. In *Linoproductus* sp., with inner side of shell pushed out. Cass limestone, Douglas group, Pennsylvanian. Southeast of Ashland, Nebraska. × 2

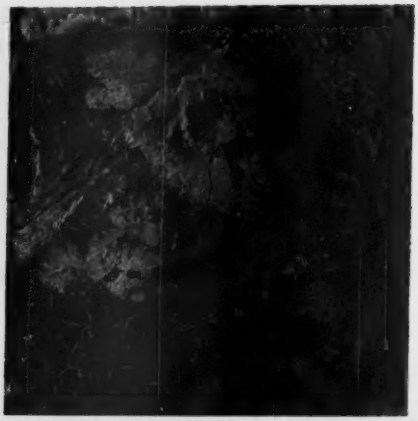
(6) Nebr. G. S. No. 421. Upper Farley limestone, Missouri series, Pennsylvanian. 1¼ mi. west of LaPlatte, Nebraska. × 10

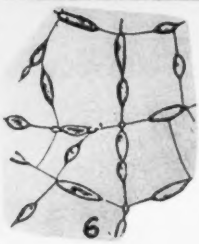
(7) *Caulostrepsis taeniola* Clark on *Stropheodonta* sp. Lectotype, New York State Museum, Albany, N. Y. From Coblentzian (Lower Devonian) of Seifen, Germany.

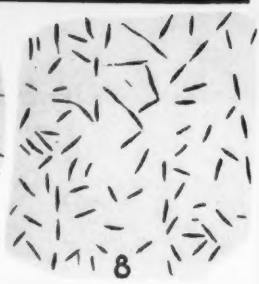
(8) *Caulostrepsis dunbari*, Nebr. G. S. No. 441. In shell of *Myalina slocomi* Sayre, with outer ostracum of the latter pushed out. Doniphan shale, Lecompton limestone formation, Shawnee group, Pennsylvanian. Pollard farm, about 1 mi. west of Nehawka, Nebraska. × 2.



BASCOMELLA AND *CAULOSTREPSIS*







BASCOMELLA AND *RHOPALONARIA*

PLATE 12.—*BASCOMELLA* AND *RHOPALONARIA*

Figure

(1) *Bascomella subsphaerica* n. sp. Holotype, Nebr. G. S. No. 449. In cast of *Rhipidomella hessensis*. Kaibab limestone, Permian. Bright Angel trail, just west of Grand Canyon Lodge, Arizona. × 20.

(2–3) *Rhopalonaria dendriformis* n. sp. Holotype, Nebr. G. S. No. 429. Indicated by arrow in the basal part of *Septopora*, attached to the inner surface of outer ostracum of *Myalina* (*Orthomyalina*) *slocomi Sayre*. Hughes Creek shale, Big Blue series, Permian. 1 mi. east of Bennett, Nebraska. Fig. 1, × 1; figs. 2, 3, × 20.

(4, 5) *Rhopalonaria graphicus* n. sp. Holotype, Nebr. G. S. No. 430.

(4) In the outer side of ventral valve of *Chonetes granulifer*. Limestone in Hughes Creek shale, Big Blue series, Permian. 3 mi. south of Stine, Nebraska. × 20

(5) Nebr. G. S. No. 442. In *Myalina* sp. Nebraska City limestone, northeast of St. Mary's, Kansas, × 20.

(6) *Rhopalonaria venosa* Ulrich. Genotype of *Rhopalonaria*. Richmond group, late Ordovician. Waynesville and Clarksville, Ohio. After Ulrich, 1895, fig. 8e, × 20 (enlarged from the original magnification × 18).

(7) *Rhopalonaria keokukensis* Ulrich and Bassler. On *Zaphrentis* sp. Keokuk formation, Mississippian. Keokuk, Iowa. After Ulrich and Bassler, 1904, Pl. LXVI, fig. 11. × 20 (enlarged from the original magnification × 9).

(8) *Rhopalonaria tenuis* Ulrich and Bassler. Hamilton formation, Devonian. Thedford, Ontario. After Ulrich and Bassler, 1904, Pl. LXVI, fig. 7; × 10 (enlarged from the original magnification × 9).

PLATE 13.—*RHOPALONARIA* AND BLISTERS AND EXCAVATIONS IN LIVING AND FOSSIL SHELLS

Figure

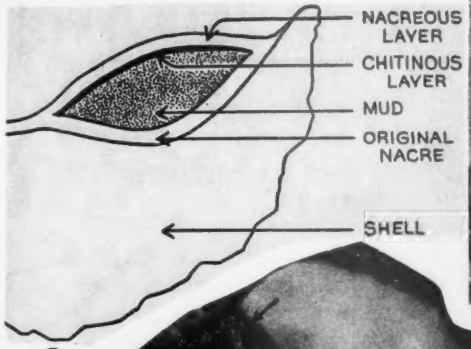
(1–2) Mud blisters on inner side of upper valve of living oyster shell formed around worm *Polydora ciliata*. After Lunz, 1941, Figs. 1 and 2 on p. 274.
(1) Inner view of shell. Blister with two etched canals indicated by an arrow. × abt. 1.
(2) Diagramatic section through shell and mud blister. Slightly magnified.

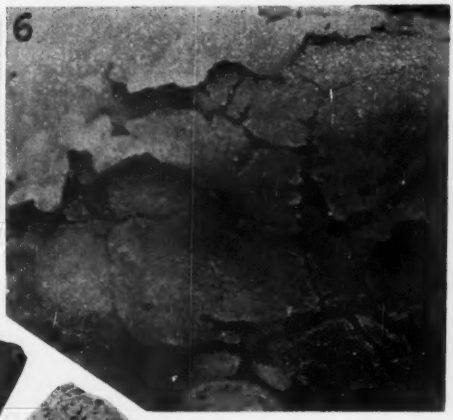
(3) Outer and inner views of living *Venus* sp. shell "showing evidence of boring sponge galleries and from which spicules of *Cliona ciliata* were obtained." After Old, 1941, Pl. II, fig. B. × ½.

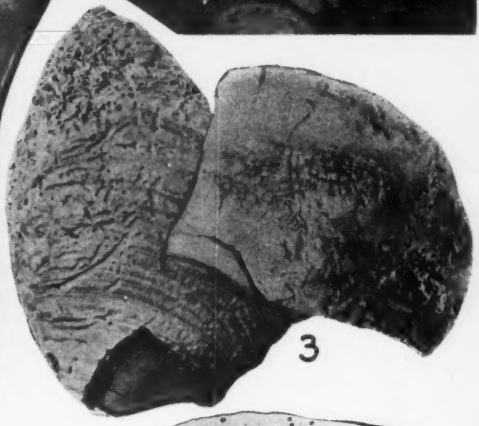
(4) Excavated chambers of boring sponge *Cliona corallinoides* Hancock "exposed by the removal of the surface" of the *Pecten maximus* shell. *a*—papillary punctures. After Hancock, 1849, Pl. XV, fig. 1. × 1.

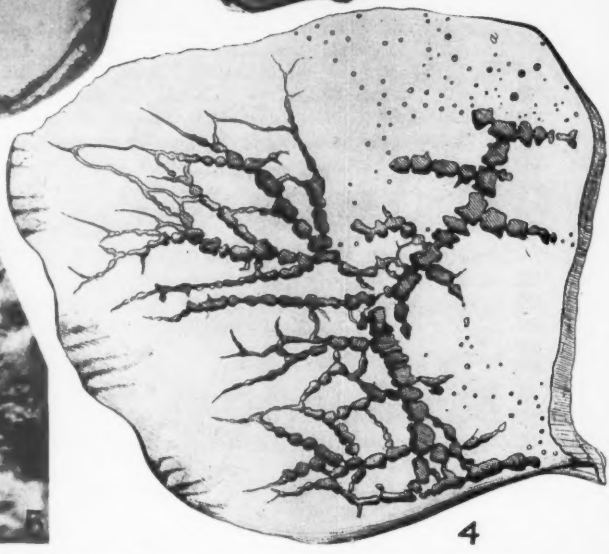
(5) *Rhopalonaria graphicus* n. sp. Nebr. G. S. No. 449. In dorsal valve of *Dictyoclostus* sp. Dover limestone, Wabaunsee group, Pennsylvanian. Cut on Highway 10, southeast of Maple Hill, Kansas. × 20.

(7) *Rhopalonaria* (?) sp. Nebr. G. S. No. 450. In back (reverse) side of *Thamniscus guadalupensis* Girty. Leonard limestone, Word Ranch, Glass Mountains, Texas. × 20.









RHOPALONARIA AND LIVING AND FOSSIL BLISTERS AND EXCAVATIONS IN SHELLS

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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CORRELATION OF THE MARINE CENOZOIC FORMATIONS OF WESTERN NORTH AMERICA

BY THE WESTERN CENOZOIC SUBCOMMITTEE, CHARLES E. WEAVER (*Chairman*), STANLEY BECK, M. N. BRAMLETTE, STANLEY CARLSON, BRUCE L. CLARK, THOMAS W. DIBBLEE, JR., WYATT DURHAM, GLENN C. FERGUSON, LESH C. FOREST, U. S. GRANT, IV, MASON HILL, F. R. KELLEY, R. M. KLEINPELL, W. D. KLEINPELL, J. MARKS, W. C. PUTNAM, H. G. SCHENCK, N. L. TALIAFERRO, R. R. THORUP, ELIZABETH WATSON, AND R. T. WHITE.

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INTRODUCTION

By Charles E. Weaver

This is Number 11 of the series of correlation charts being prepared by the Committee on Stratigraphy of the National Research Council (Dunbar *et al.*, 1942, p. 429–434.).

It has been constructed by stratigraphers and paleontologists actively engaged in both field and laboratory research and is not purely a compilation of information sought for in the literature; it has resulted from continuous scientific investigations by some of the men most active in developing present-day conceptions concerning the classification of Cenozoic formations and the interpretation of the geologic history of the Cenozoic era in this part of the globe. As more critical data are obtained concerning the lithology, distribution, and stratigraphic relations of the rock formations and their contained faunas, the interpretations of the correlation and geologic history will become modified.

Two schools of thought exist on the Pacific Coast regarding the classification of Cenozoic formations. The older of these has been developed largely through the considerations of problems involving evolutionary changes in species from the basal to top layers within a single formation or within a stratigraphic sequence of several formations in a single geographic area. Use has been made mainly of species belonging to the Mullosca, Echinoidea, and Coelenterata. Highly ornamented species of certain genera of gastropods have been compared with species from the Cenozoic formations of the Atlantic and Gulf Coastal Plains of North America as well as from Europe, and, as a result, indirect correlations have been made with certain marine faunas of Europe. These are based in part on generic resemblances and in part on close similarities of species as in the case of the Domengine of California and the Lutetian of the Paris Basin. Accordingly there has developed a tendency to use the international time scale based on the stratigraphy and faunas of Europe as a standard for comparison. However, because of the provincial nature of the Cenozoic faunas on the Pacific Coast such correlation encounters many difficulties. For the most part this is due to the lack of identical species in the two far-removed areas and to uncertainties of interpretation of the European formations by some of the European investigators.

A second school is represented by an increasing number of paleontologists who, during the past 25 years, have been making a detailed study of the Foraminifera and

their biostratigraphic relationships. To a considerable extent this has been fostered by economic application to the growth of the petroleum industry. The universities also have published important contributions to foraminiferal studies. In certain areas great thicknesses of marine strata, which are almost entirely lacking in megafossils, contain rich assemblages of Foraminifera, diatoms, and Radiolaria. In some parts of the Coast Ranges fairly complete sections of strata have been measured in great detail, and sequences of foraminiferal faunas have been collected and studied. Measured sections from different localities and their microfaunas have been compared, and a sequence of faunal zones has been established. Through this work a West Coast biostratigraphic time scale has been constructed and is extensively used by many investigators on the Pacific Coast (Kleinpell, 1938).

This cleavage into two schools, due partly to the preference of some stratigraphers for one set of materials and techniques and of others for a different set, springs largely from the inexorable fact that parts of the Cenozoic stratigraphic record in the West Coast province are rich in microfossils and almost lacking in mollusks or other large, shell-bearing groups, whereas other parts of the record are marked by abundant megafossils and few Foraminifera. Hence both schools of specialists are essential, each supplementing the work of the other, and the use of two independent schemes of classification in this province is natural if not inevitable. The two schemes can be integrated and arranged side by side, as at the left end of this chart, so that any portion of either corresponds in time with the apposed part of the other. Thus a given formation would be placed in the same position in the chart by both schools. Accordingly there is now general agreement among stratigraphers as to correlations of the Cenozoic formations within the West Coast Province.

However, when correlation with the standard section of Europe is attempted, irreconcilable differences arise between these two American schools. Hence, in the present state of our knowledge, it is not possible to use the European section as a standard against which to build this chart. It is, therefore, omitted from the left side of the chart. For convenience of general reference, however, it is inserted at the right side where it appears twice; in the first instance it indicates the correlation with the American sequence as accepted by students of megafossils, and in the second, the international correlations accepted by the micropaleontologists. There is general agreement with respect to the stages in the Eocene, but very wide divergences with respect to the position of the European stages of Oligocene and Miocene epochs. Until more information is available neither view is likely to gain general acceptance. It should be emphasized, therefore, that *the arrangement of the West Coast formations in the body of the chart was determined on the basis of local criteria and is not dependent on any inferred correlation with Europe.*

Shading by vertical lines indicates a hiatus; shading by oblique lines suggests that formations of this age may be present but concealed.

Straight lines for formational boundaries indicate that the formational limits are well dated; dashed lines and question marks imply uncertainty as to the age limits of a formation.

Many formations in the Pacific Coast region are thick—even thousands of feet thick—and they commonly show marked changes in lithology within relatively short

horizontal distances. This is due largely to the fact that the sediments accumulated in relatively small structural basins with rapidly and differentially subsiding floors. The annotations which follow are intended to give the reader who is unfamiliar with the details a minimum of data concerning the character of these formations and the basis for their correlation.

The author (or authors) of a particular column is responsible for the choice of the stratigraphic classification used but is not exclusively responsible for the correlation with other columns.

GENERAL ANNOTATIONS

1, 2. One school of contributors to this chart has based all correlations on metazoan fossil zones and has recognized one sequence of stages; columns prepared by this school bear a black triangle. In the columns prepared by the school which has relied on foraminiferal zones and has used a different sequence of stage names, a black circle is used.

In some columns the space at the top is insufficient for the names of all the contributors; in such instances they are given in the appropriate annotation.

3. The independent schemes of classification adopted by two groups of contributors to this chart have been integrated and arranged so that *any part of one corresponds in time with the apposed part of the other insofar as the American sequence is concerned.* However, the two schools disagree irreconcilably on correlation of parts of the European sequence with that of western North America. To bring out these divergences it has been necessary to insert the European standard section twice, in the first instance showing the correlation adopted by the students of metazoan fossils, and in the second that preferred by the students of protozoans. The space and position allotted to several of the European stages differ widely in these two columns, but the conflict relates only to correlation with Europe. As an example, the Zemorrian stage with two foraminiferal zones (*Uvigerinella sparsicostata* and *Uvigerina gallowayi* zones) is believed by both schools to correlate with the *Turritella inezana* zone and the lower part of the "Vaqueros stage" of western North America, but the students of Foraminifera believe it to be equivalent to the Rupelian of Europe and the students of metazoans consider it equivalent to the Burdigalian. Comparison of these two columns will reveal other such divergences with respect to European correlation. It should be emphasized, therefore, that the position and age relations of the formations shown in the body of this chart were determined on the basis of local (American) criteria and are not affected by the conflicting views with respect to European correlation.

4. The formational names "Jacalitos", "Etchegoin", "San Joaquin clay", and "Tulare" of the San Joaquin Valley are inserted in the chart so as to indicate their relation to the Pliocene microfossil zones. In a similar manner the formational names "Repetto", "Pico", "San Pedro", and "Timms Point" of the Los Angeles Basin are introduced to indicate their relation to microfaunal zones of that area. In both cases the rectangles containing these names are to be regarded as inserts and are not to be considered as parts of the columns whose headings are designated "California stages" and "Zones based on Foraminifera".

5. The Eocene microfaunal zones designated (Pl. 1) as A-1, A-2, A-3, B-1A, B-2 B-3, B-4, C, D, and E are those used by Laiming (1941, p. 192).

6. The Pliocene microfaunal zones used for the San Joaquin Valley areas are those adopted by Ferguson (1941, p. 240).

7. The foraminiferal zones used for the relatively deep water Pliocene deposits of the Los Angeles and Ventura basins are those adopted by Wissler (1941, p. 210).

8. The metazoan fossil zones correlate horizontally with the zones based on Foraminifera.

9. This classification of the Cenozoic formations into series is proposed by Schenck.

GENERAL COMMENTS ON THE CHART

By Hubert G. Schenck and Robert T. White

10. Regarding the Sparnacian as a division of the lower Eocene, Rutsch (1939) has asserted that the Sparnacian is a nonmarine facies of the Thanetian. Wrigley (1937, Pl. 18) considers the Sparnacian to be of continental origin and in part equivalent to both marine Thanetian and Ypresian.

11. In order that specialists may understand the reason for defining the Oligocene as used by Schenck and others, reference may be made to the monograph by Schenck and Reinhart (1938, p. 17–19).

H. H. Renz, a specialist on tropical American Foraminifera, made a detailed study of topotypes of the "Vaqueros" fauna described by Barbat and Von Estorff (1933, p. 164–174), and concluded (letter to H. G. Schenck, 1942) that this assemblage indicates an age not older than middle Oligocene (Rupelian) and not younger than upper Oligocene (Aquitanian).

12. The height of the spaces devoted to the Pacific Coast stages are disproportionate. No time significance is to be attached to this. The Refugian stage, for example, occupies much more space on the chart than the Zemorrian. This lack of equal spacing has been caused by the attempt to effect a compromise between the equally spaced divisions formed by the adoption of the European stages and the Pacific Slope stages as used by many micropaleontologists. Insofar as we know, the only recent attempt to determine the actual duration of any Tertiary stage is that by Bersier (1936, p. 103–108), who estimated that the Chattian-Aquitanian was an age lasting 2.5 to 3.0 million years. A common estimate of the duration of the Miocene is 20 million years.

13. Many of the faunal zones based largely on foraminiferal evidence are provisional. The Pliocene "zones" for example have not been adequately defined as time-stratigraphic units. The Eocene divisions, likewise, are not definitely established For example, Laiming (1939, p. 558, Fig. 6, and p. 559) in one important section shows that commonly accepted megafossil correlation and the correlation indicated by Foraminifera of the same unit are three "zones" apart. Finally, work on the Refugian faunas is not sufficiently advanced to warrant zonation. In order that tentative use may be made of published opinions, one may refer to the several papers in the California Division of Mines, Bulletin No. 118, preprint of part 2, August, 1941 Goudkoff (1941, p. 248, 250), Kleinpell (1941, p. 200).

14. We know of no convincing evidence to prove the precise correlation of any Ter-

tiary formation in California with formations in Europe. Different views concerning the age of the Vaqueros formation are summarized by Schenck and Childs (1942). Foraminiferal evidence suggests that the Domengine, also, may be older than Clark and Vokes indicated (1936). Cushman and Siegfus (1942, check list opp. p. 416) record *Hantkenina* cf. *dumblei* from "G" member of the type Kreyenhagen shale. The subgenus to which this species belongs is said by Thalmann (1942, Table 2) to be restricted to the Lutetian, but in Table 1 he shows the species as occurring in the Ledian, or what is approximately Auversian. The inference is that the type Kreyenhagen is older than Bartonian. Independent confirmation comes from H. H. Renz (letter to Schenck, 1942) who studied a foraminiferal sample from the lower Kreyenhagen and expressed the opinion that it is no younger than Lutetian.

Regarding the age of the Briones sandstone, VanderHoof (1941, p. 1984–1985) has shown that a species of fossil vertebrate in "Santa Margarita beds", which Schenck believes to be lower Delmontian and younger than the Briones, is the same as one described from the Tortonian of Europe. Previously the Delmontian was thought to correlate with the Sarmatian stage.

If the San Ramon is lower Zemorrian, as R. W. Kleinpell (1938) believed, then the San Ramon may be correlated with the Rupelian, following Schenck and Childs (1942, p. 14). Clark, however, believes that the San Ramon is the correlative of the Aquitanian. Others hold the view that the San Ramon is undoubtedly Miocene.

Other examples might be given of conflicting opinions regarding the ages of Californian formations in terms of the European ages. Therefore, since the paleontologic evidence so far adduced offers no certain means of correlating precisely the western American marine strata with European stages, the use of the European terms on this chart is for the purpose of general orientation rather than an expression of our views on precise synchronization.

ANNOTATIONS

LOWER CALIFORNIA-COLORADO DESERT AREA

By J. Wyatt Durham

15. "Unnamed": exposed in Colorado Desert area. Unconformable on Palm Spring formation and unconformably overlain by sediments of Pleistocene Lake Coahuila. Nonmarine and brackish-water sediments including red and green mudstones, siltstones, sandstones, and conglomerates, up to 8600 feet thick, with a zone of *Mulinia pallida* (Broderip and Sowerby) 500 feet above the base. The microfauna includes ostracods and small Foraminifera similar to those living in the Salton Sea. Recently mapped by L. G. Tarbet.

16. The fauna of the basal Imperial formation is the same as that of the lower part of the Salada group. The middle member of the Salada group may in turn be correlated on the basis of identical species of Mollusca with the San Diego formation as exposed at Pacific Beach. Because of the apparent close relationship of the members of the Salada group, all are considered to be Pliocene. Nevertheless, the possibility is admitted that the lower Salada, and consequently the Imperial, may be as old as upper Miocene. They cannot be older since the Salada group rests with marked unconformity on the Comondú.

17. Comondú formation: widespread in the Peninsula of Lower California from the southern end north to about Lat. 29° 30′. Unconformable on older formations, including the Isidro, and unconformably overlain by the Pliocene. Largely volcanic but becoming finer to the west. Apparently all nonmarine.

18. Isidro formation: widely distributed on western side of southern half of the Peninsula of California. Soft calcareous sandstones and sandy clays with a maximum thickness of about 500 feet. Locally, at least, unconformable on San Gregorio formation and overlain with a widespread unconformity by the Comondú formation. Best-known fauna correlates with the Vaqueros-Temblor transition fauna of California, but the formation may also contain correlatives of both the Vaqueros and the Temblor.

19. San Gregorio formation: local exposures, largely on western side of the southern half of the peninsula of Lower California. More than 500 feet of fine-grained sandstone, sandy shale, interbedded diatomaceous sediments, and cherty beds. Overlain unconformably by younger beds. Same species of *Cornwallius* as in Sooke formation of Vancouver Island.

20. Tepetate formation: local exposures in southern part of peninsula of Lower California. Largely sandstone. A *Discocyclina* indicates probable middle or upper Eocene age.

21. Sepultura formation: exposed along the western side of the peninsula of Lower California from Lat. 30° to 31° 15′. Composed of sandstones, conglomerates, and some shales. Fauna equivalent to that of the "Martinez" of California.

SAN DIEGO REGION

By U. S. Grant, IV

22. This column is based upon the work of L. G. Hertlein and U. S. Grant. A brief summary has been published already (1939). An attempt has been made to correlate this column with the California standard column based largely on metazoans but not with the one proposed by R. M. Kleinpell and adopted by H. G. Schenck *et al.*

23. The Bay Point formation is a low terrace covering of sand and gravel, locally highly fossiliferous. The warm-water fauna and low elevation suggest a possible correlation with some part of the Palos Verdes formation of the Los Angeles region. It is of late Pleistocene age.

24. The Sweitzer formation is a higher terrace capping of predominantly brownish sandstone and conglomerate which is, insofar as known, unfossiliferous, though it may be partly marine. It is generally from 3 to 10 or 15 feet thick and occurs commonly upon the San Diego, Otai, and Linda Vista mesas where it rests unconformably upon the Eocene or Pliocene. It may be of late Pliocene or early Pleistocene age.

25. The San Diego formation is predominantly a grayish sandstone with occasional gravel lenses. The upper part is in places noticeably micaceous. Bentonite occurs interstratified with the sandstone in the southern part of the region, becoming thicker toward the Mexican boundary. Abundant fossil mollusks and some echinoids indicate a middle Pliocene age. It varies in thickness up to a maximum of possibly 2000 feet. It overlies unconformably the Eocene and Pliocene or overlaps onto the older crystalline rocks.

26. The Poway formation is primarily a nonmarine conglomerate and sandstone

which may attain a thickness of 1000 feet. Rare marine fingers in the lower part contain fossils indicating equivalence to a part of the type Tejon. This formation is well exposed in the canyons north of the San Diego River Valley.

27. The Rose Canyon shale of Eocene age reaches a thickness of about 300 feet and is widely distributed north of the San Diego River Valley, but farther south it is encountered only in wells. It rests conformably on the Torrey sand or overlaps onto older rocks. Abundant fossils indicate a Domengine age though the upper part may be equivalent to the Sierra Blanca limestone of the Santa Ynez Mountains and the Matilija of the Ojai-Sespe gorge area.

28. The Torrey sand member of the La Jolla formation reaches a maximum thickness of about 200 feet. It may be equivalent in age to the Ione sand and homotaxial if not synchronous with certain so-called "glass sands" in the Coast Ranges of California.

29. The Delmar (Hanna, Marcus, 1926, p. 208), the lowest member of the La Jolla formation, consists of greenish, gray, or reddish sandstone or sandy shale, commonly cross-bedded or lenticular, with poorly preserved marine fossils locally in the lower portion, and sporadic layers of fossil leaves in the upper portion. Its lower contact has not been seen. It may correlate with the lower part of the Llajas formation (the silt member above the Llajas conglomerate, the latter being probably equivalent to basal Capay).

30. The Cretaceous sedimentary rocks are poorly exposed in the San Diego region. They outcrop along the ocean shore at Point Loma and also at and near La Jolla. They are probably over 500 feet thick, but their lower contact is not exposed. Lithologically they vary from brownish to gray sandstone to dark carbonaceous shales. Fossils indicate an upper Senonian (Campanian) age, Upper Cretaceous.

WEST SIDE OF LOS ANGELES BASIN (PALOS VERDES HILLS)

By M. N. Bramlette

31. The outcrop section of this area is much thinner than that encountered by drilling within the Los Angeles Basin as the Pico formation is missing and the others are thinner and of somewhat different lithology.

32. The Palos Verdes and earlier marine terrace deposits occur at elevations up to 925 feet above sea level.

33. The San Pedro sand here includes the Timms Point siltstone "facies" or member and the Lomita calcareous "facies" or member.

34. The Pico formation is entirely missing here but consists of 1500–2500 feet of sandstone and sandy shale in the basin to the north and east.

35. The Repetto formation is dominantly siltstone and thin with some of the microfaunal zones missing, as compared with the thickness of about 1000–4000 feet in various parts of the Los Angeles Basin.

36. The Malaga mudstone is about 6000 feet thick.

37. The Monterey (Modelo) formation includes an upper Valmonte diatomite member that is about 750 feet thick and the Altamira shale member of dominantly porcelaneous shale that is 600–1200 feet thick and overlaps onto the Mesozoic basement rock.

SIMI VALLEY AREA

By U. S. Grant, IV

38. The Simi Valley section is based largely on the unpublished investigations of Frank B. Tolman, though the present author will assume the responsibility for disputable interpretations.

39. The Llajas formation appears to extend from basal Capay to Sierra Blanca inclusive (just below Tejon). The Sierra Blanca is the lower part of the "Transition" of Clark and Vokes and represents the time of widespread middle Eocene seas with *Discocylina californica* Schenck, *D. psila* Woodring, *D. cloptoni* Vaughan, *Dictyconus* sp., *Amblypygus subhemisphericus* Israelsky, *Eoagassizia alta* A. Clark, and other forms, some of which suggest a correlation with the Chiapas fauna of Gardiner and Bowles and the Saint Bartholomew limestone of the West Indies.

The upper Llajas (largely shale except the uppermost 170 feet which is called the olive silt member) on the north side of Simi Valley contains four beds of glauconite within 280 feet of shale above the lower Llajas. The upper Llajas is probably equivalent to some part of the "Juncal" and the Matilija. The conglomerate member at the base of the Llajas formation is probably equivalent to the basal part (Zone I) of the Capay.

40. The upper part of the Santa Susana is probably equivalent to Meganos "D". The lower part is probably Paleocene, a regressive phase of that epoch in California.

CANADA DE SANTA ANITA SECTION

By T. W. Dibblee, Jr., F. R. Kelley, and Hubert G. Schenck

41. The type locality of the Refugian stage is in the unusually complete and well-exposed sequence of strata cropping out in this part of the Santa Ynez Range, Santa Barbara County.

42. Insufficient space to include names of all authors.

43. The Anita shale, "Matilija" sandstone, "Cozy Dell" shale, and Sacate sandstone are described by Kelley (1943). These four formations here aggregate 3700 feet in thickness.

44. The original definition of the Gaviota formation is by Effinger (1936, p. 351), and the Refugian stage by Schenck and Kleinpell (1936, p. 218–219). The type Gaviota formation totals 1585 feet in thickness.

45. Above the Gaviota formation is 525 feet of massive sandstones, conglomerates, and sandy shales which are referred to locally as the "Marine Sespe formation". *Ostrea tayloriana* and a few other mollusks occur in these beds.

46. The "Vaqueros" formation is a transgressive, cross-bedded pebbly sandstone about 100 feet thick. It carries *Pecten magnolia* and other mollusks.

47. The Rincon clay shale, about 1400 feet thick, overlies the "Vaqueros" sandstone and carries a Zemorrian and Saucesian foraminiferal fauna.

48. The "Monterey" shale is about 1300 feet thick and consists of soft to hard siliceous shales and thin limestones, and about 5 feet of bentonite at the base. The formation is divisible into six lithologic units, and all foraminiferal zones from uppermost Saucesian to upper Mohnian are represented.

49. The "Monterey" shale is disconformably overlain by the Sisquoc formation, consisting of brown splintery shales with a few feet of tar-soaked siltstone and conglomerate at the base. Organic remains consist mainly of diatoms and sparse Foraminifera of probable Delmontian age. Only the lower 800 feet is exposed here, but at Pt. Conception about 3000 feet is exposed.

SANTA MARIA BASIN

By M. N. Bramlette

50. The Orcutt sand is the earliest of the terrace deposits and is tilted around the structural uplifts of the area.

51. The Paso Robles consists of nonmarine sand and gravel with some thin clay and fresh-water limestone beds in the lower part and has a thickness up to 2000 feet.

52. The Careaga sandstone includes an upper member of sandstone and conglomerate (Graciosa member) that is 25–425 feet thick and a lower member (Cebada) of fine-grained sandstone that is 0–1000 feet thick.

53. The Foxen mudstone consists of 0–800 feet of mudstone, siltstone, and some thin sandstone beds.

54. The Sisquoc formation consists of 150–3000 feet of diatomaceous mudstone. In the near-shore facies along the Sisquoc River, it includes the Tinaguais sandstone member or tongue that is 350 to 1400 feet thick.

55. The Monterey shale is about 1000–2000 feet thick and consists dominantly of cherty and porcelaneous shales with some diatomaceous shale in the upper part locally.

56. The Point Sal formation consists of 150–1500 feet of mudstone, siltstone, and thin sandstone beds.

57. The Lospe formation consists of nonmarine sandstone and sandy shale that is red and includes conglomerate beds in the lower part and is dominantly green in the upper part. It rests on the Mesozoic "basement" rocks.

CALIENTE MOUNTAINS

By U. S. Grant, IV

58. This column is generalized and emasculated from the columns given in the paper by Eaton et. al. (1941). It represents a section on the scarp, summit, and northeast slope of Caliente Mountain between Cuyama Valley and Carrizo Plain. On the southwest side of Cuyama Valley a series of echinoid-oyster faunas permit of fine stratigraphic subdivisions of what is generalized here into Monterey formation.

59. The Vaqueros formation as here used are primarily brownish-weathering sandstones containing the *Turritella inezana* fauna so well described by Loel and Corey (1932).

NIPOMA QUADRANGLE

By N. L. Taliaferro

60. "Etchegoin formation": greenish-gray silts and sands about 700 feet thick.

61. Santa Margarita formation: sands and white siliceous shales 2500 feet thick.

62. "Monterey formation": a series of organic shales with limestone lentils and silty shales; sandy toward the base.

63. Vaqueros formation: a heterogenous series of white sandstones, foraminiferal silts, and dark ferruginous conglomerates.

64. Sespe formation: a series of continental sandstones, shales, and conglomerates, variegated in color.

EAST SIDE OF SALINAS VALLEY SOUTH OF KING CITY

By Bruce L. Clark

65. Paso Robles formation: A thin veneer of coarse gravels and sand which, southwest of King City, rest directly upon the King City formation; farther south these deposits overlie the Poncho Rico formation.

66. Poncho Rico formation: The type section at Poncho Creek consists largely of sandstones and sandy shales which are several hundred feet in thickness.

67. King City formation: This formation is 1000 feet thick. The basal beds consist of 0–300 feet of coarse sandstone which rest unconformably upon the granite basal complex. Overlying this is 600–700 feet of white silty shales.

SANTA CRUZ MOUNTAINS COLUMN

By Lesh C. Forest and Hubert G. Schenck

68. Insufficient space to include initials of authors.

69. This area is critical geographically, as the outcropping formations comprise a northern, well-developed coastal Tertiary sequence in California. Further, it is important paleoecologically, as the unique, medium-depth facies of the Oligocene-Miocene formations constitute a correlative tie-point between the shallower, southern-latitude faunas of California and the northern-latitude, medium-depth faunas of Oregon and Washington. Finally, it is fortunate that the type Oligocene of California is in this area because of the wealth of faunal data that permit the Eogene-Neogene stratigraphic sequence to be subdivided into biostratigraphic divisions.

For the sake of completeness, we have included in this composite column the "Martinez" of San Mateo quadrangle. Some workers have considerable doubt concerning the age of these strata. The latest contribution is a paper by Hanna and Hertlein (1939).

70. The Purisima formation at its type locality rests unconformably on Monterey shale. Elsewhere it overlaps older rocks. Locally, the formation may be as old as the type Jacalitos.

71. The Santa Margarita sands seem to constitute a large lens in the Monterey shale. VanderHoof (1941) has described from these sands a sea cow which he holds to be the same species as a fossil described from the Tortonian stage of Europe. Stratigraphically, about 140 feet above the beds containing the sea cow occur numerous echini which Schenck thinks are upper Delmontian—an echini assemblage fall-in the *Astrodapsis antiselli* zone. About 150 feet below the Santa Margarita sands on Zayente Creek, David Gray collected Foraminifera which R. M. Kleinpell determined to be Luisian. Recognizable Mohnian fossils have not yet been found in this

section, though it may be that strata of this stage are present. VanderHoof thought that the Santa Margarita sands were unconformable upon the subjacent Monterey shale.

72. The Monterey formation of this area is 5000 feet thick. Foraminiferal faunas of upper Relizian age at the base of the formation and the fossils above-mentioned suggest that most, if not all, of the monterey is restricted to the Miocene series, unless the upper part is early Pliocene.

73. A bluish-gray siltstone member near the top of the Vaqueros formation (about 2700 feet thick) of the Santa Cruz Mountains is characterized by Saucesian (probably upper) Foraminifera. However, foraminiferal faunas in shale 520 feet above the base of the Vaqueros formation have been allocated to the Zemorrian stage. *Pecten sanctaecruzensis* Arnold, an "index fossil" for the so-called transitional Oligocene-Miocene beds as mapped by Branner *et al.* in 1909 has been found only in the lower 5 feet of the Vaqueros formation.

74. The upper 2275 feet of the San Lorenzo formation contains a Zemorrian foraminiferal fauna, described in part by Cushman and Hobson (1935) and Kleinpell (1938). Many of the distinctive, medium-depth species of the megafauna have been found only in Oregon and Washington in the Lincoln and Blakeley formations.

75. Foraminiferal assemblages have been collected recently by Forest from the lower 680 feet of the San Lorenzo formation. These assemblages belong in the Refugian and unnamed stages. The San Lorenzo formation at its type area, therefore, is both Eocene and Oligocene in age.

76. The upper Butano formation, at least, is to be assigned to the "*Plectofrondicularia jenkinsi* zone." The occurrence of this fossil was recorded by Schenck in 1936 (p. 69).

77. Detailed studies of the so-called "Chico formation" along San Francisquito Creek, San Mateo County, a short distance northeast of Searsville Lake, have disclosed the presence of foraminiferal shale. The species have been identified by Lois T. Martin, who considered them Eocene. This has been confirmed by several other micropaleontologists.

The limestone inclusions in the diabase dikes, as described in the Santa Cruz folio, have not been investigated by recent workers. Schenck is dubious regarding the Eocene age of all the inclusions.

78. Mention of the "Martinez" of the San Mateo quadrangle has been made above.

SOUTH END OF SAN JOAQUIN VALLEY

By S. Beck, S. Carlson, M. Hill, and J. Marks

79. Insufficient space to include names of all authors.

80. The South End of San Joaquin Valley section is a composite of exposed sediments (highly deformed and of variable lithology), which extend from 20 miles west of to 6 miles east of Highway 99 (in Grapevine Canyon), between the alluvium of the Valley and the granitic rocks of the San Emigdio and Tehachapi Mountains. The area is stratigraphically important because it contains the type sections of the Tecuya, Pleito, San Emigdio, and Tejon formations.

81. A prominent angular unconformity occurs between the fluviatile terrace and "Tulare" deposits.

82. Angular unconformity occurs between the marine "Etchegoin" sands and the marine "Mariocopa" shale. This hiatus is filled northward under alluvium by Pliocene and Miocene marine sands and shales.

83. The micro-organic siliceous "Maricopa" shale rests with sharp transitional contact on the marine "Temblor" clay shale.

84. The "Vaqueros" marine sandstone occurs with rapid transitional contact below the "Temblor" shale. Basic lava and pyroclastics occur within or below the "Vaqueros" or above or within the Tecuya fluviatile formation (eastward equivalent of "Vaqueros" and (?) "Temblor" formations).

85. The Pleito marine shale and sandstone occurs with apparent conformity between the "Vaqueros" and San Emigdio marine sandstone formations and grades eastward into the Tecuya formation.

86. The Tecuya fluviatile formation has possible important unconformities within it and rests unconformably on successively older strata eastward until in contact with the granitic rocks.

87. The Tejon formation occurs conformably below the San Emigdio formation or unconformably below the Tecuya beds; it is divisible into lithologic and faunal units and it lies on pre-Tertiary granitic basement.

EAST SIDE SAN JOAQUIN VALLEY, BAKERSFIELD, CALIFORNIA

By Glenn C. Ferguson

88. This column is exposed in the area east and northeast of Bakersfield, California. The youngest beds, other than terrace deposits along the margins of present and ancient stream beds, are composed of land-laid deposits of the Kern River "series." In well sections the Kern River "series" has been divided into two main subdivisions. The Kern River formation, or upper portion of the "series", is Pliocene and Pleistocene in age, and represents a facies of equivalent marine and brackish-water beds deposited farther out in the valley. The lower division of the "series", the Chanac formation, as recognized in well sections drilled in the Bakersfield area, is composed of those land-laid beds resting on the "Santa Margarita sand" and underlying the marine Pliocene strata. The marine Pliocene has not been recognized in outcrop, nor has it been found in all the well sections. The presence of this marine finger is the surest means of distinguishing between the two formations. In outcrop there may be a slight lithologic or mineralogic variation. Generally speaking, however, they are mapped as one formation or one cartographic unit.

89. The "Santa Margarita formation" immediately underlies the Chanac in outcrop and is resting directly upon beds mapped as Round Mountain siltstone. As determined from the well section, however, this sand rests progressively on older beds toward the east. The evidence is insufficient to be certain whether this sand rests unconformably on older beds or whether the sand itself becomes progressively older up dip, representing a facies equivalent to shales down dip. Certainly in outcrop it is separated by an unconformity from the underlying Round Mountain silt and older beds still farther to the north and east. The exact age of the "Santa Margarita sand" in outcrop in the Bakersfield area, as compared to the time stratigraphic section of California, is not known. It may be as high as the lower Delmontian or as low as lower Mohnian. At present it is thought to be Delmontian.

90. With the exception of the upper portion of the Round Mountain silt, this member was deposited during a part of both the Relizian and Luisian ages of deposition. The upper 10 or 15 feet of the Round Mountain silt in outcrop consists of a "shark-teeth-and-bone" bed and may represent very early lower Mohnian. The base of this bed may rest unconformably on the remaining portion of the upper Round Mountain silt. The Round Mountain silt thickens rapidly westward, in well sections, to a point where all or nearly all the Relizian and Luisian time stages of deposition are represented. In the outcrop section in the immediate vicinity of Round Mountain and northward, all but the lower portion of the Round Mountain silt is nearly barren of Foraminifera. A short distance down dip in well sections, beds which can only be the equivalent of the upper portion of the exposure (excepting the "shark-teeth-and-bone" bed) contain a fauna equivalent in age to the lower Luisian, but higher beds contain Foraminifera equivalent to the upper portion of the Luisian; this portion may possibly be cut out by unconformity in outcrop. Southeast of Round Mountain, beds are exposed which actually contain specimens of *Valvulineria californica* Cushman, (*sensu stricto*) a species typical of the Luisian stage.

91. The Olcese sand can be divided into three parts. The upper part represents strictly a basal sandy facies of the Round Mountain silt, and it is marine. This portion rests with apparent disconformity upon the middle nonmarine member which contains an abundance of coarse, cross-bedded detrital material together with pumice stone and petrified wood. Although marine in origin, the lower portion is very fine and ashy and probably represents an upper facies of the underlying Freeman. The upper part of the Olcese Sand is Relizian in age. The middle part is either Relizian or upper Saucesian, while the lower part may belong to the Saucesian stage of deposition.

92. The Freeman-Jewett member of the California lower Miocene belongs to the Saucesian stage. Originally the Freeman-Jewett member was divided into two portions. The upper part was termed the Freeman, which represented an ashy facies, with the lower part representing a sandy silt facies more or less devoid of ash. It was found, however, that the division was purely arbitrary, and no consistent marker could be found to distinguish consistently one from the other. Thus, they have been included as one member, called the Freeman-Jewett. In the lower portion of the Freeman-Jewett a very sandy facies is present which is locally termed Pyramid Hills sand. This varies in thickness and rests immediately upon the Vedder sand except for 8 to 10 feet of separating tight, gritty siltstone.

93. Vedder sand is locally exposed only in the region north and east of the Round Mountain area. These exposures are limited and often are not very thick. However this sand, in the well sections down dip toward the west, is considerably developed and expanded compared to the outcrop section. The Vedder sand in well sections actually consists of an upper and lower sand separated by a siltstone member ranging in thickness approximately from 25 to 200 feet. While none is exposed, a fairly thick series of sand and shale has been penetrated below the first Vedder sand in well sections. These beds have sometimes been referred to as the "Vedder" or even the "Vedder formation". The entire thickness belongs to the Zemorrian stage of de-

position. A part of the Vedder sand, as found in well sections, may be represented in outcrop by a nonmarine facies often incorrectly referred to as the Walker formation.

94. The Walker formation in outcrop underlies unconformably the basal Miocene beds. The unconformity is distinct at Pyramid Hill with an approximate divergence in dip of 15°. The Walker, as exposed in the Bakersfield area, is believed to be upper or middle Eocene in age, or both. This age assignment is based on its stratigraphic relationship to beds of known age rather than on paleontologic evidence. In outcrop, the Walker is nonmarine in character, but it appears to interfinger with marine Eocene beds in well sections to the west. The older interpretation that the Walker interfingers with basal Miocene beds has proven erroneous. The Walker rests unconformably upon basement rocks of varying and undetermined age.

REEF RIDGE-KETTLEMAN HILLS AREA

By Hubert G. Schenck and Robert T. White

95. This area is important because it is near a major oil field and many geologists and paleontologists have devoted much study to it. Many species of invertebrates and vertebrates have been described from this district. The character of the formations, thicknesses, and other relevant data are given by Woodring *et al.* (1940). Finally, the area is important because its geographic location places it in a key position in correlating the formations in the southern with those in the northern San Joaquin Valley.

There is a possibility that the "*Planulina pseudowuellerstorfi* zone" and the "*Amphimorphina californica* zone" are zonules characterized by facies faunules and are not true zones, or at least that they rank no higher than sub-zones of the subjacent and superjacent zones. This point is brought up because these two "zones" are not present between the Avenal and Kreyenhagen, and yet the physical relationship of these two formations does not support the existence of a hiatus of the relative magnitude indicated on the chart (Pl. 1). Another possibility, for which we have no evidence, is that one or both of the two "zones" is represented by the barren glauconitic sands at the base of the Kreyenhagen.

96. Stanley Siegfus believes that the upper part of the Kreyenhagen on Reef Ridge should be placed in some part of the *Uvigerina cocoaensis* zone, lower Refugian. We follow him in this decision.

97. That the lower Temblor formation on Reef Ridge is older than Relizian is suggested in several ways. Siegfus reports *Pecten perrini* Arnold from the basal sands. Possibly an unconformity may exist within the Temblor formation at the base of the Relizian part of the section, as shown in the Tumey Gulch-Domengine Creek column.

The mineral uvarovite found in the Big Blue is also found in the upper part of the Temblor formation in one section on Reef Ridge. This suggests that at least locally on Reef Ridge the Temblor may extend up into the Luisian. It is significant that VanderHoof (*in* Schenck and Childs, 1942, p. 40–42) holds that the *Desmostylus*-bearing levels of the Briones and Temblor are approximately equivalent in time.

98. The age of the McLure shale is not settled. R. M. Kleinpell (1936, correlation chart) placed an assemblage from the lower 15 feet of the McLure in the *Bulimina*

uvigerinaformis zone of the Mohnian. Ferguson (1941) claims that the beds carrying this assemblage are unconformable beneath the main part of the McLure shale and that most of the McLure is Delmontian.

TUMEY GULCH-DOMENGINE CREEK AREA

By Hubert G. Schenck and Robert T. White

99. In the Tumey Gulch-Domengine Creek area thick sections of fossiliferous lower Tertiary strata are exceptionally well exposed in a homocline bordering the west side of San Joaquin Valley for a distance of over 30 miles. Excellent exposures in addition to data from deep well bores in the adjacent valley make possible detailed stratigraphic studies over a large area. Geographically this area forms an important "tie in" for Eocene and Paleocene strata between Simi Valley, Mt. Diablo, and other regions. Finally, because this area is in the "belt of variables" as used by Marr (1929, pp. 75, 89) much light is thrown on problems of facies changes, conditions during deposition, and other matters.

100. The Miocene formations are thin, shallow marine to brackish-water deposits with many overlaps which may be regarded as typical of deposits at the margin of a basin of deposition.

The "Big Blue" member of the Temblor formation, 0 to 850 feet thick is composed almost entirely of serpentine fragments ranging in size from clay particles to blocks many feet in diameter. The source is the Franciscan formation 6 miles distant at the nearest point.

101. The part of the Temblor immediately below the Big Blue contains specimens of the species of horse, *Merychippus californicus*, in beds which are in close stratigraphic proximity to those containing well-known marine molluscan faunules. This part of the Temblor may fall in the Hemingfordian or Barstovian stage of the vertebrate paleontologists (Wood *et al.*, 1941). R. M. Kleinpell (1938, p. 155) expressed the belief that the "*Merychippus* zone" north of Coalinga may be within the uppermost limits of the Relizian stage. Indirect evidence thus suggests that the beds discussed are late Burdigalian or early Helvetian in age, but R. A. Stirton (letter of Schenck, 1943) places the *Merychippus* beds in the Barstovian stage and correlates them with the upper Tortonian or lower Sarmatian. Granted this, the upper part of the Temblor in this locality cannot be younger than Burdigalian.

VanderHoof (1937, p. 202) records *Desmostylus* from beds stratigraphically slightly below *Merychippus* quarry. He also reports (1937, p. 201) the sirenian associated with "*Scutella*" *merriami*.

102. The Kreyenhagen shale is composed of brown organic shales containing numerous diatoms and Foraminifera and about 1000 to 2500 feet thick. This is the maximum thickness for this formation in the San Joaquin Valley. The maximum development of Kreyenhagen lithology is in the Ciervo Hills area. The brown shales of the Kreyenhagen crop out over more than 10,000 square miles in California.

John Zimmerman, Jr., in an unpublished report, has pointed out the marked similarity between the type Tumey sandstone and the type Wheatland sandstone. The mineral assemblage in each is remarkably alike.

103. The Domengine sandstone, 5 to 200 feet thick, is a transgressive unit

composed mostly of coarse sediments with minor amounts of shale and abounds in excellently preserved Eocene Mollusca and Foraminifera.

104. The Lodo formation is composed mainly of gray clay shale abounding in well preserved Foraminifera and Mollusca which occur locally in a few sandy lenses. The Lodo varies in thickness from 1100 feet to somewhat more than 6000 feet, including the Cantua sandstone member. Excellent exposures and the unbroken great thicknesses of abundantly fossiliferous strata make this formation important in establishing biozones for the Paleozoic and parts of the Eocene.

105. It would not be possible in a brief note to give an adequate idea of the fossils in the Lodo formation which may have interregional significance.

In the upper part of the Arroyo Hondo shale are fossiliferous beds commonly called "*Spiroglyphus* reefs". Also in this part of the section are abundant specimens of *Discocyclina clarki* (Cushman). The "*Spiroglyphus*" is *Tubulostium*, which Gardner (1939) and Rutsch (1939 [1940]) have recently studied. A thin fossiliferous sandstone in the lower half of the Cerros shale at Salt Creek contains *Turritella andersoni andersoni* Dickerson and other molusks. This bed is placed by Clark and Vokes (1936) in the "Capay stage".

At the base of the Lodo formation near Silver Creek is the best-preserved Paleocene marine molluscan assemblage on the Pacific slope of North America. In it are specimens of *Cucullaea mathewsonii*, a large *Venericardia*, *Priscofusus caudatus*, *Eocypraea martini*, *Eomilthia*, n. sp., and many others. The beds containing this assemblage correlate with the basal part of the type Martinez formation (Watson, 1942).

SOUTH SIDE OF MOUNT DIABLO

By Bruce L. Clark

106. Tassajero formation: The type section south and southeast of Mount Diablo consists largely of lacustral deposits, mostly sandstones and shales with thin beds of fresh-water limestones. At the base is 200 to 300 feet of volcanic ash referred to as the "Moraga tuff".

107. Green Valley formation: a heterogeneous series of continental deposits, may be in part lacustral; thickness 300 feet. A large vertebrate fauna from basal beds.

108. Diablo formation: new name for Alamo formation. Consists of coarse arkosic sandstones; a heavy conglomerate at the base composed mostly of andesitic boulders, lenses of conglomerate higher up; also thin layers of shale carrying abundant leaf impressions; thickness about 1000 feet.

109. Neroly formation: sandstones and shales; marine and brackish water, fossiliferous at many horizons; thickness 2000 feet.

110. Cierbo sands: mostly coarse gray arkosic marine sandstone, lenticular conglomerates, and conglomeratic sandstones; thickness 1000 feet.

111. Briones sands: coarse gray arkosic sandstones; conglomeratic in places, thickness 350 feet.

112. "Monterey formation": gray-brown massive sandstones; a heavy conglomerate at the base, and one near the middle.

NORTH SIDE OF MOUNT DIABLO

By Bruce L. Clark

113. San Pablo group: a series of beds which have been divided into two formations, the Cierbo sands and the Neroly formation: composed mostly of sandstone with conglomerates at the base and lenticular conglomerate layers in middle and upper portion, with considerable volcanic ash in lower portion.

114. Kirker tuff: fine white volcanic ash with sandy layers; thickness about 400 feet.

115. Kirker sandstone: gray arkosic sands about 50 feet thick unconformably upon the Markley formation. Thickness, 50 feet.

116. Markley formation: arkosic brownish-gray micaceous (muscovite) sandstone alternating with carbonaceous shales in middle and lower portion. The sandstones predominating; in the upper portion an organic shale 700 feet thick with radiolarians and Foraminifera; maximum thickness 4000 feet.

117. "Nortonville shales": shales and sands between the Markley formation and the "Domengine formation". Consists of four shales and five sandstone members, shales predominating.

BERKELEY HILLS-STRAWBERRY CANYON AREA

By Bruce L. Clark

118. Siesta formation: a series of lacustrine beds; mostly shales and sandstones with thin lenses of fresh-water limestones. These beds are about 200 feet thick; they overlie the Moraga basalts and are overlain by the Bald Peak basalts.

119. Orinda formation: continental beds; conglomerates, sandstone, and sandy shales, which are variegated in color, with several fossiliferous lenses of marine sandstone which contain several species distinctive of the upper Miocene. These beds appear to be at least in part equivalent to the Neroly formation (upper Miocene). Vertebrate fossils found in the continental beds fit in with the correlation.

SAN PABLO BAY AREA

By C. E. Weaver

120. The shales and sandstones of the "Monterey formation", the Briones sandstone, Cierbo sandstone, and Neroly formation of the San Pablo group, together with the overlying Pinole tuff, lie in the San Pablo syncline and are exposed in the sea cliffs along San Pablo Bay.

121. The Briones sandstone of this area is marine and consists of upper and lower sandstone members with an intermediate shale designated as the Hercules shale member. The lower sandstone averages 1100 feet thick, and the upper sandstone 850 feet. The shale member is 550 feet thick. The cleanly washed quartzose yellowish-brown sandstone is medium- to fine-grained and contains local lenses of grit, fine conglomerate, and sandy clay shale. The Hercules shale member is a siliceous light-brownish-gray rock which weathers into splintery fragments and occasionally is sandy.

122. The Cierbo sandstone of marine origin and approximately 900 feet thick is

composed in the lower part of alternating layers of fine- and coarse-grained sandstone and white tuff. The upper part consists of yellowish- to brownish-gray concretionary sandstone and subordinate amounts of sandy clay shale.

123. The Neroly sandstone where exposed in the San Pablo syncline is approximately 1250 feet thick and contains marine invertebrate fossils. It is composed of interstratified coarse-grained massive bluish-gray sandstones, fine-grained gray sandstones, and subordinate amounts of light-brown shale.

124. The name Pinole tuff is applied to exposures of this rock along Pinole Creek and in the San Pablo syncline at Rodeo. The rock is composed of about 1000 feet of pumiceous tuff of andesitic composition and is interbedded with fresh-water deposits of gravel, sand, and clay. Fossil vertebrates from these beds at Rodeo are regarded by Stirton as of lower Pliocene age.

125. Nearly horizontal deposits of sand, clay, and gravel, which grade upward into alluvium, occur in raised beaches at several places around the shores of Carquinez Strait and San Pablo Bay. These deposits contain several species of mollusks which are still living along the Pacific Coast of California and probably are in part contemporaneous with the Millerton formation exposed father west of Tomales Bay.

MARTINEZ AREA-PACHECO SYNCLINE

By Hubert G. Schenck, Elizabeth A. Watson, Bruce L. Clark, and C. E. Weaver

126. Insufficient space to include names of all authors.

127. The stratigraphic importance of this area is threefold: (1) It is the type area of the Martinez formation, (2) it is important because much of the early paleontologic and stratigraphic work in California dealt with the beds exposed on the two limbs of the Pacheco syncline, and (3) the Martinez and "Tejon" formations of this syncline alone will probably include nearly, if not all, the zones of the Paleocene, lower and middle, and part of the upper Eocene of California.

128. The latest report on this section is by Watson (1942).

129. The Martinez formation rests unconformably upon the "Chico" formation in this section. The upper part of this "Chico" is older than the moreno formation at its type locality.

130. Mollusks usually regarded as Paleocene occur in the lower 500 feet of the Martinez formation on the southwest flank of the syncline.

131. On the northeast flank of this syncline, *Turritella pachecoensis* occurs within 200 feet of the base. *Flabellum remondianum*, *Mesalia martinezensis*, and other Paleocene species are about 500 feet above the base, and *Pholadomya* nasuta is present at a horizon about 1100 feet above the base. From the available data, we infer that the thickness of Paleocene (as used on the Pacific Coast of North America) strata is thus about 1100 feet in this area.

132. Workers agree that the upper part of the type Martinez formation is younger than Paleocene.

133. Foraminifera in the lower 250 feet of the "Tejon" formation suggest a correlation of this part of the section with the Canoas silt (basal) member of the Kreyenhagen formation.

134. We are not sure whether the basal part of the "Tejon" of this syncline or the

upper part of the Martinez formation should be correlated with the type Domengine formation.

135. On the northeast flank of this syncline, however, about 800 feet above the base of the "Tejon", are several beds full of *Turritella uvasana aedificata*, which is also abundant in sandstone of the "Domengine stage" on the south side of Mt. Diablo.

136. The upper part of the "Tejon" occupies the same stratigraphic position and has the same foraminiferal species at the top as does the Markley formation at its type locality.

137. The unconformity at the base of the San Ramon on the southwest flank of the syncline was unusually well exposed in a fresh road cut at the time our studies were made in this district.

COMPOSITE SECTION NORTH OF SAN FRANCISCO BAY

By C. E. Weaver

138. The type section of the Millerton formation, approximately 60 feet thick, is exposed on the north shore of Millerton Head on the east side of Tomales Bay about 3 miles northwest of Point Reyes Station. It is composed of conglomerate, brownish-gray soft sandy shale, and clayey sandstone, together with interbedded layers of gravel which contain species of marine mollusks living at the present time off the coast of California south of Monterey Bay. These strata lie within the zone of the San Andreas fault and are moderately disturbed.

139. The Sonoma volcanics ranging from 50 to 2000 feet thick consist of lava flows tuffs, agglomerates, and flow breccias which are mainly andesitic but locally basaltic, Associated with these are ocasional beds of gravel, clay, and sandstone and also thick. flows of rhyolite and tuff especially near the top of the sections. These volcanic materials have an extensive areal distribution in the hills adjacent to Napa and Sonoma valleys and also in the lower part of Russian River Valley.

140. The Wilson Ranch beds about 600 feet thick are exposed in low hills on the east side of Russian River 6 miles south of Healdsburg. They consist of thick-bedded friable yellow to buff-colored sandstone, fine conglomerate, and shale containing marine molluskan fossils. They are interbedded with the lower part of the Sonoma volcanics.

141. The Petaluma formation approximately 3000 feet thick is composed of strongly folded light-brown massive and stratified sandstones and pebbly conglomerates with interbedded greenish-gray clay shales which are exposed in an elongate area 1 to 2 miles wide along the northeast side of Petaluma Valley. The formation contains fresh and brackish-water molluscan fossils.

142. The "Tolay volcanics" are nowhere exposed at the surface but have been encountered in a well drilled on Adobe Creek 3 miles northeast of Petaluma. They occur beneath the Petaluma formation and were penetrated at depths from 2223 to 5964 feet. The petrographic information concerning these lavas is based entirely upon well cores. They consist of basalts, andesites, breccias, and tuffs.

143. The massive bluish-gray to steel-gray coarse- to medium-grained sandstone exposed in the cliffs along Carneros Creek between Napa and Sonoma are correlated with the Neroly formation north of Mount Diablo. These rocks are similar faunally

and lithologically and at Carneros Creek dip westward unconformably beneath the Sonoma volcanics.

IONE AND WHEATLAND AREAS OF THE GREAT VALLEY

By Bruce L. Clark

144. Wheatland formation: The conglomerate at the base of this formation contains large andesitic boulders; marine molluscan fossils found in the matrix between the boulders show that the formation belongs to a zone equivalent to that of the Keasey formation of Washington and a portion of the lower Gaviota formation of California. It is believed that the andesitic boulders were derived from the Reeds Creek andesites which are exposed a few miles north of the town of Wheatland. Roughly estimated, the Wheatland formation is between 250 and 300 feet thick.

145. Ione formation: a heterogeneous series of gravels, sands; shales and volcanic ash in places; grade into auriferous gravels. A marine molluscan fauna of middle Eocene age has been found in this series of beds at several localities. The Reeds Creek andesites are closely associated with beds believed to be of Ione age.

ROSEBURG AREA

By C. E. Weaver

146. The type section of the Tyee formation is located at Tyee Mountain in the northwest corner of the Roseburg quadrangle where it is approximately 5000 feet thick. It consists of massive micaceous sandstones with subordinate amounts of shale. Turner has reported from this formation *Venericardia hornii* subsp. *calafia* Stewart and *Turritella uvasana hendoni* Merriam var. A, which are considered as index fossils.

147. The type section of the Umpqua formation occurs along north Umpqua River about 17 miles northeast of Roseburg. It consists of 4400 feet of marine sandstone, shale, and conglomerate which rests upon a series of lava flows, tuffs, and sediments which may belong within the formation.

148. The lowest members of the Eocene sections in numerous areas south and southwest of Roseburg consist of basic lava flows, agglomerates, and tuffs with associated sediments. Similar rocks are exposed at many places northward in the Coast Ranges to Vancouver Island where they are considered as equivalent to the Metchosin formation. The exposures generally occur along the axes of deeply eroded anticlines.

COOS BAY AREA

By C. E. Weaver

149. The type sections of the Arago, Bassendorf, Tunnel Point, and Empire formations occur in the west limb of a prominent syncline at Coos Bay, Oregon. The Arago formation originally named and described by Diller locally was later divided into the lower or Pulaski formation and the upper or Coaledo formation for the purpose of distinguishing the coal-bearing beds from the non-coal bearing beds.

The Arago formation used in the original sense as proposed by Diller is 8400 feet

thick and consists of alternating members of brownish-gray sandy clay shales, medium- and coarse-grained sandstones, shaly sandstones, and occasional layers of conglomerate. Marine fossil Mollusca are fairly abundant in many beds from the base to top of the formation.

150. The Bassendorf formation is exposed in the sea cliffs along Bassendorf Beach between Yokam Point and Tunnel Point south of the entrance to Coos Bay. The formation consists of 1500 feet of micaceous sandy clay shale, siltstones, thin layers of sandstone, and tuffaceous massive sandy shales. Megafossils are very scarce, but Foraminifera are abundant in certain layers. The Foraminifera suggest an uppermost Eocene age although previously these beds were considered lower Oligocene.

151. The Tunnel Point sandstone, which is 350 feet thick where exposed in the sea cliffs just north of Tunnel Point, is probably conformable on the Bassendorf shale but is definitely unconformable beneath the Empire formation. It consists of massive brown sandstone, laminated sandstone, and subordinate amounts of interstratified sandy clay shale all of which contain marine invertebrate fossils.

152. The Empire formation exposed in the sea cliffs at the south entrance to Coos Bay is about 800 feet thick and is composed of brownish-gray massive concretionary medium- to coarse-grained moderately indurated sandstone. The formation is exposed also on the east side of Coos Bay where it is abundantly supplied with marine invertebrate fossils. The Coos conglomerate is a lens within the Empire formation.

COMSTOCK AREA

By C. E. Weaver

153. The type section of the Comstock formation is exposed in railway and highway cuts from 1 to 2 miles southwest of Comstock, Oregon. The formation consists of about 1000 feet of nonmarine micaceous sandstones, shaly siltstone, and light-colored tuffs, some beds of which contain fossil plants. The basal beds rest unconformably upon marine Eocene strata, and the upper part is probably unconformable beneath the Fisher formation.

154. The name Fisher formation was applied by Schenck (1927, p. 451, 459) to a section about 1500 feet thick composed of rhyolitic tuff and agglomerate together with nonmarine clays, sands, and gravels. It is exposed near Eugene, Oregon, in sec. 12, T. 18 N., R. 5 W., where it rests on Eocene sandstones and is overlain unconformably by the Eugene formation.

YAQUINA BAY AREA

By C. E. Weaver

155. Oligocene and middle Miocene formations are well exposed in the cliffs along the north shore of Yaquina Bay and in the sea cliffs just north along the ocean. Here occur the type sections of the Toledo and Yaquina formations and the Nye shale. Unconformable upon the Nye shale are the marine sandstones and basalts of the Astoria formation.

156. The Toledo formation is 3450 feet thick and composed of moderately fine-grained massive brownish-gray to grayish-brown sandy clay shales, which contain

marine invertebrate fossils. The Foraminifera from the Moody shale, which is a member of the Toledo formation, contains species which, according to Schenck, are closely related to those in the Keasey formation which is now thought to be at least in part uppermost Eocene.

157. The Yaquina formation, which rests in probable conformity upon the Toledo formation, is 3100 feet thick. It is exposed for 4 miles along the north shore of Yaquina Bay and is composed of coarse-grained brownish-gray massive micaceous sandstones in the lower half and fine- to medium-grained grayish-brown sandstone in the upper half. It contains a marine invertebrate fauna which is largely contemporaneous with that of the Lincoln formation of Washington.

158. The Nye shale, conformable upon the Yaquina formation, is about 3000 feet thick and is composed of massive to slightly stratified dark-gray sandy clay shale. Foraminifera from the upper beds of the formation are considered by R. M. Kleinpell to show a close similarity to those in the lower Miocene of Kern County, California, and to the Blakeley formation of Washington.

EUGENE AREA

By C. E. Weaver

159. In ascending order the Spencer, Comstock, Fisher, and Eugene formations are exposed in the hills southwest of Eugene, Oregon, where they are all separated by probable unconformities. The Comstock and Fisher formations already have been described.

160. The name Spencer formation was applied by Turner (1938, p. 23) to shales and sandstones containing marine molluscan faunas with species similar to those in the lower part of the Cowlitz formation in Washington. The type section occurs about 10 miles southwest of Eugene and is composed of tuffaceous sandstone and shale.

161. The Eugene formation, exposed at several localities south of Eugene, Oregon, consists of approximately 5000 to 7500 feet of sandstone, sandy shale, conglomerate, and tuff. It is unconformable upon the Fisher formation and also beneath the Miocene or Pliocene lavas which continue eastward into the Cascade Mountains. The marine molluscan faunas have been correlated in part with the faunas of the Lincoln formation of western Washington which have been regarded as middle Oligocene. Paleobotanical evidence from the fossil floras at Goshen which occur stratigraphically above the beds containing the marine faunas on the southeast side of Spencer Butte suggests a possible Eocene age (Chaney and Sanborn, 1933, p. 59–64).

COLUMBIA COUNTY, OREGON, AREA

By C. E. Weaver

162. Certain sandy tuffaceous bluish and dark-colored marine shales exposed in the railway cuts and banks of Rock Creek near Keasey, Columbia County, Oregon, were named the Keasey formation by Schenck (1927, p. 457; 1928, p. 36). These strata, at least 500 feet thick and possibly 1000 feet, contain several species of fossil mollusks and a rich fauna of Foraminifera closely related to the *Uvigerina cocoaensis* zone.

163. The Pittsburg Bluff formation originally was described by Diller (1896, p. 466) and further discussed by Schenck (1928, p. 36–37). It consists of massive gray medium-grained and somewhat tuffaceous sandstone with subordinate amounts of shale which crop out in the banks of Nehalem River near Pittsburg, Columbia County, Oregon. Exposures in the hills between Pittsburg and Rock Creek suggest unconformable relations between these beds and the underlying Keasey formation. Marine molluscan fossils are abundant in certain layers.

164. Both the Keasey and Pittsburg Bluff formations are overlain unconformably by basaltic lavas which were poured out contemporaneously with the deposition of the middle Miocene Astoria formation although the sediments of this formation are not present in the upper Nehalem Valley.

SOUTHWEST WASHINGTON

By C. E. Weaver

165. In southwestern Washington a thick section, consisting of the Metchosin volcanics and the Keasey, Lincoln, and Astoria formations, has been folded and deeply eroded so as to expose over 3000 feet of the Metchosin volcanics without penetrating to their base. The Keasey formation rests unconformably on the volcanics and lithologically is similar to the beds of the same formation at the type section in Oregon. The overlying Lincoln formation is about 6000 feet thick and fossiliferous throughout.

166. The Astoria formation exposed in the hills surrounding the Willapa River Valley ranges from 3500 to 4000 feet thick and consists mainly of brownish-gray moderately indurated medium-grained sandstone with interstratified shaly sandstone layers all of which contain a fairly abundant marine molluscan fauna. Thin intercalated flows of basalt are present near the ocean but become thicker and more numerous toward the east where they constitute more than 75 per cent of the formation. The Astoria formation rests unconformably upon the Lincoln formation.

GRAYS HARBOR COUNTY

By C. E. Weaver

167. As in southwestern Washington the Metchosin formation is exposed along eroded anticlinal axes and rests unconformably on older formations in the south flanks of the Olympic Mountains.

168. The type section of the "Lincoln" formation is a composite of numerous sections exposed in the banks of Chehalis River between Centralia and Porter, Washington, and in the hills southwest of these towns. In the bank of Chehalis River at Galvin Station 5 miles west of Centralia the well-known and well-preserved marine fauna occurs in the upper two thirds of the lower half of the formation. The fauna from the "Porter beds" near Porter is derived from strata in the middle part of the Lincoln formation. The formation as a whole is composed of brownish-gray medium-grained shaly and tuffaceous sandstone. The basal grits and conglomerates at Oakville and in the upper part of Porter Creek rest directly on the Metchosin volcanics and contain the marine molluscan fauna referred to as the "*Arca merriami* zone". These basal strata grade up into the typical sandstones of the Lincoln formation.

169. The Astoria formation in this area is about 4000 feet thick and is lithologically similar to that in southwestern Washington. It rests unconformably on the Lincoln formation.

170. The Montesano formation is a composite from numerous sections exposed in the banks of Wynoochee and Wishkah rivers and their numerous tributaries. The maximum exposed thickness is 2800 feet, but still younger beds farther west are concealed beneath thick deposits of Pleistocene gravels and sands. At certain localities the formation is unconformable on the Astoria and Lincoln formations; its relation to the younger Quinault formation is concealed.

171. After the close of Astoria time western Washington and Oregon were subjected to intense deformational movements; the sea withdrew to some place west of the present shore line. The Astoria formation together with the older Tertiary sediments and volcanic materials were folded into major northwest- and southeast-trending anticlines and synclines and elevated above sea level. This interval was followed by vigorous erosion and the ultimate development of an extensive plain which extended west of the present coast. During late Miocene and early Pliocene local broad downwarps developed which were invaded by the sea. The sea did not advance contemporaneously into all these gulfs and embayments, but at different times during the Pliocene and perhaps late Miocene marine deposits accumulated which have been described as the Montesano, Quinault, Empire, and Wildcat formations. The times of regression of these seas also were not contemporaneous. Consequently, the Pliocene formations named are not entirely correlative.

172. The Quinault formation is exposed in sea cliffs near the mouth of Quinault River and consists of about 950 feet of massive sandy shale, brownish-gray sandstone and alternating layers of conglomerate and sandstone, all containing marine fossils. The basal part of the Quinault formation is concealed but probably grades down into the upper part of the Montesano formation. It may represent later deposition in the Montesano Basin after the shore line had retreated farther westward.

COWLITZ RIVER BASIN

By C. E. Weaver

173. The type sections of the Cowlitz and Gries Ranch formations are exposed in the banks of Cowlitz River and Olequah Creek. The Cowlitz formation is composed of about 8000 feet of marine grayish-brown sandstone and sandy shale containing well-preserved molluscan fossils in many layers from the base to the top of the section. The type section is in the banks of Olequah Creek and not in the banks of Cowlitz River. The best known fauna of the formation does occur in about 200 feet of strata exposed in the bluffs of Cowlitz River, 1½ miles east of Vader, and corresponds to strata in the middle of the type section on Olequah Creek.

174. The marine fossiliferous beds of the Cowlitz formation exposed along Coal Creek in Cowlitz County are areally disconnected from the exposures in the Cowlitz River basin, and, although fossiliferous from base to top, the lower third of the section may be a little older.

175. The type section of the Gries Ranch beds consists of two small areas in the south bank of Cowlitz River between the towns of Toledo and Vader. It is separated

from other exposures of Tertiary rocks by a thick covering of Pleistocene sands and gravels. The exposed part of the formation is approximately 500 feet thick and consists of brownish-gray medium-grained marine sandstone and interstratified layers of grit and fine conglomerate. The stratigraphic relations to the underlying Cowlitz formation are entirely concealed. The formation at the type locality lies in the synclinal nose of a northwestward-plunging syncline.

PUGET SOUND BASIN

By C. E. Weaver

176. The Puget Sound basin has resulted from diastrophism which was especially active during the early part of upper Miocene time and again at the close of the Pliocene. During the Pleistocene it was occupied by a thick lobe of southward-moving ice, which later left the region covered with thick deposits of sands, clays, and gravels. This topography has been modified by stream erosion. In several localities in the middle part of the basin isolated exposures of the Metchosin volcanics, Oligocene sedimentary rocks, and marine, fresh-water, and brackish-water sandstones and shales of the Puget group project up through this thick glacial mantle. All these rocks are strongly folded and faulted, but it is difficult to connect the structures from one isolated locality to another.

177. The Metchosin volcanics at one time covered the area of the Olympic Mountains, but as a result of uplift during the Miocene and at the close of the Pliocene the middle part has been removed by faulting, folding, and erosion causing a horseshoe-like rim of steeply tilted flows to form high ridges on the north, east, and south margins. Late Miocene compressional movements produced a major northwest-southeast-trending anticlinal upwarp which crossed the middle part of the area of the present Puget Sound basin and extended across the present site of the Cascade Mountains into eastern Washington. During the Pliocene this was strongly sculptured by erosion. At the close of the Pliocene strong deformational movements caused north and south structural units to be superimposed upon the older northwest and southeast units. This brought into being the present-day Olympic Mountains as a part of the Coast Ranges and also the Puget Sound basin and the Cascade Mountains of Washington and Oregon. The anticlinal upwarp which extended into eastern Washington was strongly warped downward into the Puget Sound basin, and today its remnants are represented by the Wildcat Hills (2000 feet) in Kitsap County and the steeply tilted Oligocene strata along the entrance to Bremerton Navy Yard, and in the area southeast of Seattle.

The Metchosin volcanics are similar in composition to those in southwest Washington and on the eastern side of the Olympic Mountains are at least 3000 feet thick. They form the surface exposures in the Wildcat Hills but are indifferently represented in the eastern part of the Puget Sound basin. They may be equivalent in part to the Teanaway basalts of eastern Washington which are also exposed in the western slopes of the Cascade Mountains east of Seattle.

178. The Puget group is exposed in the canyons of Green and Carbonado rivers in the eastern part of the basin where it consists of three lithologic members all of which contain coal seams. The lower and middle members contain subtropical fossil floras

which suggest a lower or middle Eocene age but which as yet have not been studied sufficiently to warrant a more detailed correlation. The upper member of the group as exposed southeast of Seattle contains interstratified fossiliferous marine layers containing species of mollusks characteristic of the Cowlitz formation. The Puget group is exposed in the western foothills of the Cascades northward into British Columbia and southward into Oregon, but the lithology changes from place to place. It probably was deposited by major westward-flowing streams upon the eastern border of the rapidly but differentially subsiding late Eocene Cowlitz trough whose middle part was largely below sea level.

179. The type section of the Blakeley formation, about 8000 feet thick and exposed in low sea cliffs along Bremerton Inlet, is composed of interstratified members of conglomerate, well-bedded sandstones, sandy shales, and thinly bedded layers of alternating sandstone and shale. The well-known marine invertebrate molluscan fauna from Restoration Point occurs near the base of the upper third of the formation and is probably correlative with the lower half of the Twin River formation exposed along the Strait of Juan de Fuca on the north side of the Olympic Mountains. At the close of Blakeley time the seas withdrew from the site of the present Puget Sound Basin.

NORTH SIDE OF OLYMPIC MOUNTAINS

By C. E. Weaver

180. The Metchosin volcanics, Crescent formation, Lyre conglomerate, and the Lincoln, Twin Rivers, and Astoria formations are exposed in sea cliffs along the south shore of the Strait of Juan de Fuca where they occur in the eroded limbs of a westward-plunging syncline.

181. The Metchosin volcanics, nearly 3000 feet thick, are a southward extension from beneath the Straits of Juan de Fuca of the type section on Vancouver Island. The upper part of the succession of volcanic flows grades into tuffs and interstratified dark sandy shales containing marine invertebrate fossils. These upper and partly sedimentary beds have been named the Crescent formation but vary in lithology when followed away from the type area at Crescent Bay. Foraminifera from the type locality have been regarded by Berthiaume (1938) as suggesting correlation with the Capay formation of California.

182. The Lyre conglomerate, about 500 feet thick, consists of firmly cemented massive medium- to coarse-grained conglomerates which rest on the Crescent formation. About 6000 feet of rather massive, sandy clay shales rest in turn on the Lyre conglomerate and contain a marine molluscan fauna similar to that found in the Lincoln formation in southwestern Washington.

183. The Twin Rivers formation, ranging from 3000 to 4000 feet thick, rests on the Lincoln formation and is composed of massive shaly sandstones and interstratified thin layers of sandstone and shale. The fauna occurring in the lower half of these beds is correlated with that at Restoration Point in the type section of the Blakeley formation; the upper half of the formation is younger.

184. The Astoria formation, approximately 12,000 feet thick and exposed in the sea cliffs between Clallam Bay and Pysht, is composed of massive sandstones, conglom-

erates, shaly and pebbly sandstones, and interstratified clay shales. It rests unconformably on the Twin Rivers formation. At one time these beds were termed the "Clallam formation".

NORTHEASTERN OLYMPIC PENINSULA

By J. Wyatt Durham

185. Detailed studies in the Quimper Peninsula and adjacent areas by the present author have shown the presence of a nearly complete section of moderately well exposed fossiliferous lower and middle Oligocene sediments. In this and adjacent areas a thick section of Eocene rocks together with sufficient fossils to indicate their age is found. As a result of these studies a sequence of faunal zones, generally recognizable throughout Oregon and Washington, has been defined for the lower half of the Oligocene, with most of the type localities in the Quimper Peninsula area.

186. "Unnamed shale": about 600 feet of fossiliferous sandy shales, exposed on Marrowstone Island, overlain by glacial drift and resting on the Quimper sandstone. The fauna includes *Turritella porterensis* Weaver.

187. Quimper sandstone: a massive bedded sandstone, about 900 feet thick, unconformable on the older Oligocene and Eocene rocks. Highly fossiliferous at the base and moderately so above. Includes the type localities of the *Molopophorus stephensoni*, *M. gabbi*, and *Turritella* n. sp. zones.

188. Townsend shale: exposed on beach north of Woodmans Wharf. About 65 feet of gray-black shale with occasional nodular calcareous beds. Contains Foraminifera and some Mollusca indicating a correlation with the Keasey shale of Oregon. Rests on Lyre conglomerates and unconformably overlain by Quimper sandstone.

189. Lyre conglomerate: easternmost exposures of this formation. Missing on eastern side of Quimper Peninsula, present on western side, and several thousand feet thick a few miles to the west. Consists largely of well-worn pebble conglomerates but more cobbly toward the base. Unconformable on older basalts, agglomerates, sandstones, and sandy shales.

190. "Crescent formation": a thick sequence of basalts, agglomerates, sandstones, shales, and local limestone lenses. In this area there is apparently an upper and lower "group" of basalts, with an intervening interval largely of shales and sandstones. *Turritella uvasana* subsp. *elequahensis* Weaver and Palmer was found at one locality in an interbedded limestone lens in the upper basalts, apparently indicating a correlation with the Cowlitz formation. Foraminifera from the shales on Marrowstone Island indicate a middle Eocene age equivalent to that of the Canoas silt of California.

VANCOUVER ISLAND AREA

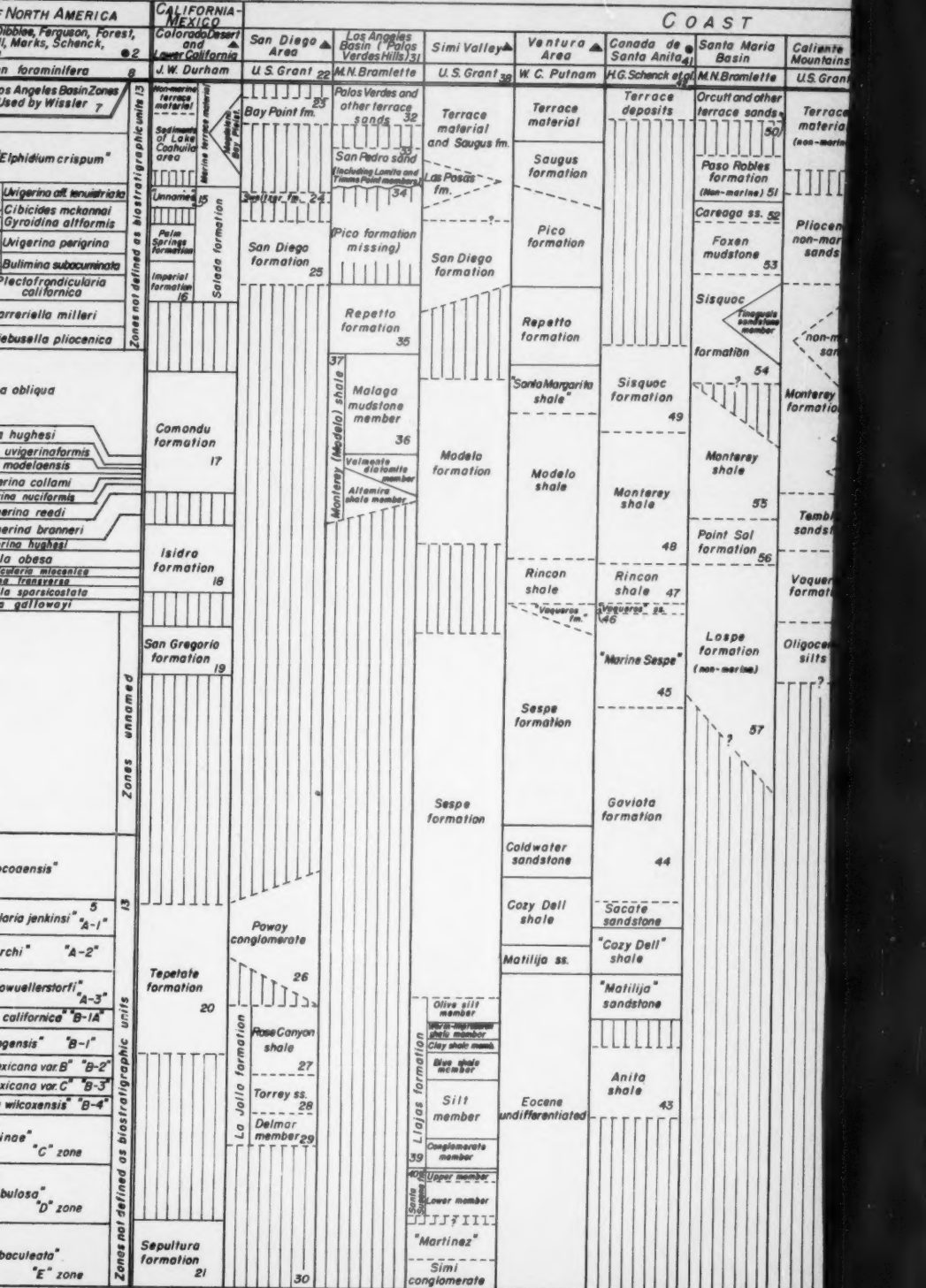
By C. E. Weaver

191. The type section of the Metchosin volcanics, first described by Clapp (1912; 1913; 1917), forms an area 30 by 85 miles on the southeastern part of Vancouver Island. These lavas rest on a complex of old igneous and metamorphic rocks and have a thickness ranging from 3000 to 5000 feet. They are composed of basaltic and andesitic flows together with pyroclastics, agglomerates, tuffs, and intrusive sills and

STANDARDS FOR CENOZOIC CORRELATION USED ON PACIFIC COAST OF NORTH AME

Classification used by Clark, Durham, Grant, Putnam, Taliaferro and Weaver ▲1		Classification used by Beck, Carlson, Dibblee, Ferguson, Hill, Kelley, R. M. Kleinpell, W. D. Kleinpell, Merks, Schen... Tharup, Watson and White					
Stages or Formations	Zones based largely on metazoans 8	4	California Stages		Zones based on foraminifera		
Terrace material		PLEISTOCENE	Upper	"A" (Unnamed)	San Joaquin Valley Zones Used by Parker and Stand... "G"	4	Los Angeles Basin Used by Wissler
Tulare			Lower "Tulare"	"B" (Unnamed)	No forams present	San Pedro Timms Pt.	"Elphidium crisp...
San Joaquin clay	Pecten coalingensis	PLIOCENE	Upper San Joaq. Etchegoin	"A" (Unnamed)	Eponides sp. A	Pico	Upper: Uvigerina alt. tenu... Cibicides mcka... Gyroidina altif...
Etchegoin	Turritella vanvleeki		Middle Etchegoin	"B" (Unnamed)	Eponides sp. "B" / Eponides exigua		M.: Uvigerina parig...
							L.: Bulimina subacu...
Jacalitos	Astrodapsis peltoides		Lower "Jacalitos"	"C" (Unnamed)	Nonionella cushmani	Repetto	Plectofrondicul... californica
	Astrodapsis antiselli						Karreriella mille...
							Liebusella pliocc...
Neroly	Astrodapsis tumidus	Delmontian		Upper	Bolivina obliqua		
Cierbo	Echinarachnius gabbi			Lower	Bolivina hughesi		
"Briones" 14	Astrodapsis brewerianus	Mohnian		Upper	Bulimina uvigerinaformis		
				Lower	Bolivina modelaensis		
		Luisian		Upper	Siphogenerina collami		
				Lower	Siphogenerina nuciformis		
"Temblor"	Echinarachnius merriami	Relizian		Upper	Siphogenerina reedi		
	Pecten andersoni barkerianus			Lower	Siphogenerina branneri		
					Siphogenerina hughesi		
"Vaqueros"	Turritella inezana santana	Saucesian		Upper	Uvigerinella obesa		
				Lower	Plectofrondicularia miocenica / Siphogenerina transversa		
	Turritella inezana ss.	Zemorrian		Upper	Uvigerinella sparsicostata		
				Lower	Uvigerina galloway...		
"Blakeley"	Echinophora apta	Refugian					
	Echinophora rex						
"Lincoln"	Turritella porterensis						
	Turritella n. sp.						
	Molopophorus gabbi						
	Molopophorus stephensoni						
Keasey	Turcicula columbiana			Lower	"Uvigerina cocoaensis"		
"Tejon"	Turritella olequahensis	Unnamed		Upper	"Plectofrondicularia jenkinsi"		
	Turritella sargenti			Middle	"Uvigerina churchi" "A...		
	Turritella uvasana ss.						
"Transition" beds	Turritella applini			Lower	"Planulina pseudowuellerstorfi"...		
"Domengine"	Turritella lawsoni	Unnamed		Upper	"Amphimorphina californica" "B...		
				Lower	"Cibicides coalingensis" "B...		
"Capay"	Galeodea susanae	Unnamed		Upper	"Marginulina mexicana var. B"		
				Middle	"Marginulina mexicana var. C"		
				Lower	"Pseudouvigerina wilcoxensis"...		
	Turritella andersoni	Unnamed			"Bolivina applinae" "C" zon...		
"Meganos"	Turritella meganosensis	Unnamed			"Gümbelina globulosa" "D" zon...		
"Martinez"	Turritella pachecoensis				"Marginulina subacuteata" "E" zon...		

NOTE: The employment of two different standards of classification at the left side of the ch... at first seem confusing to the reader; it is therefore suggested that the person consulting t... should first read the introduction in the accompanying text.

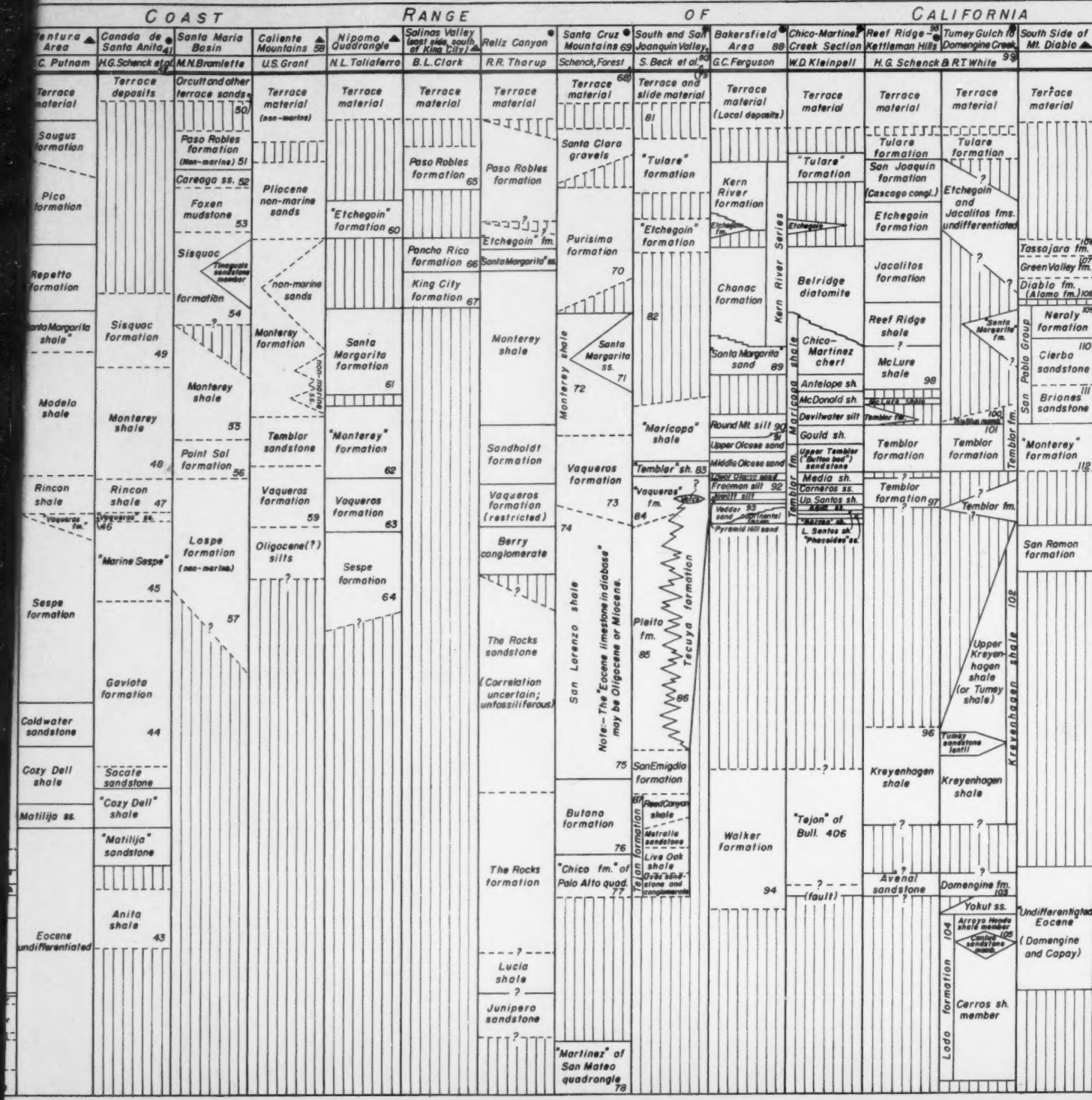


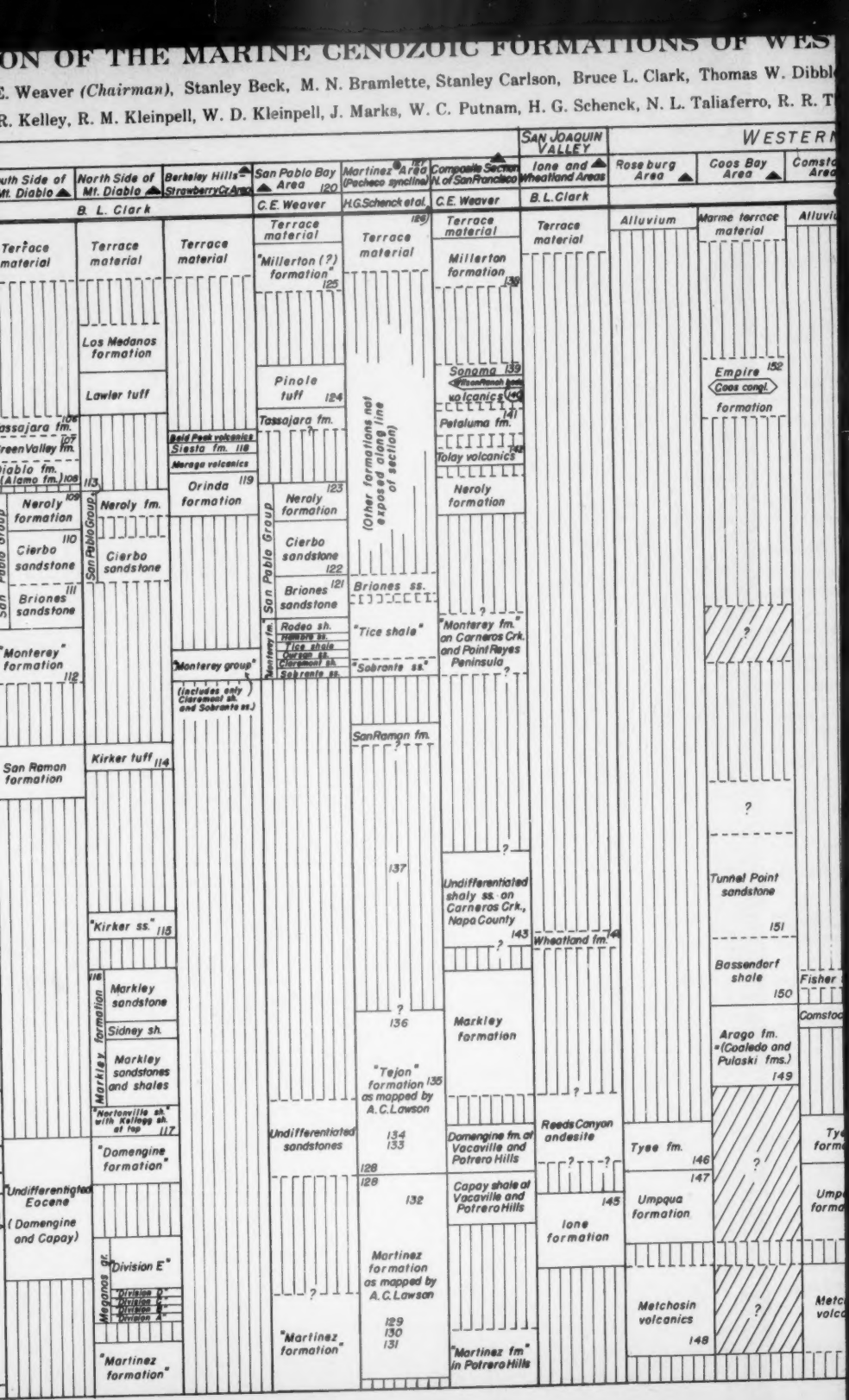
standards of classification at the left side of the chart may
is therefore suggested that the person consulting the chart
the accompanying text.

CHART No. 11 - CORRELATION C

By the Western Cenozoic Subcommittee, Charles E. Weaver
Lesh C. Forest, U. S. Grant, IV, Mason Hill, F. R. Kelley,

COAST RANGE OF CALIFORNIA




ON OF THE MARINE CENOZOIC FORMATIONS OF WES
E. Weaver (Chairman), Stanley Beck, M. N. Bramlette, Stanley Carlson, Bruce L. Clark, Thomas W. Dibbl
R. Kelley, R. M. Kleinpell, W. D. Kleinpell, J. Marks, W. C. Putnam, H. G. Schenck, N. L. Taliaferro, R. R. T
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forma
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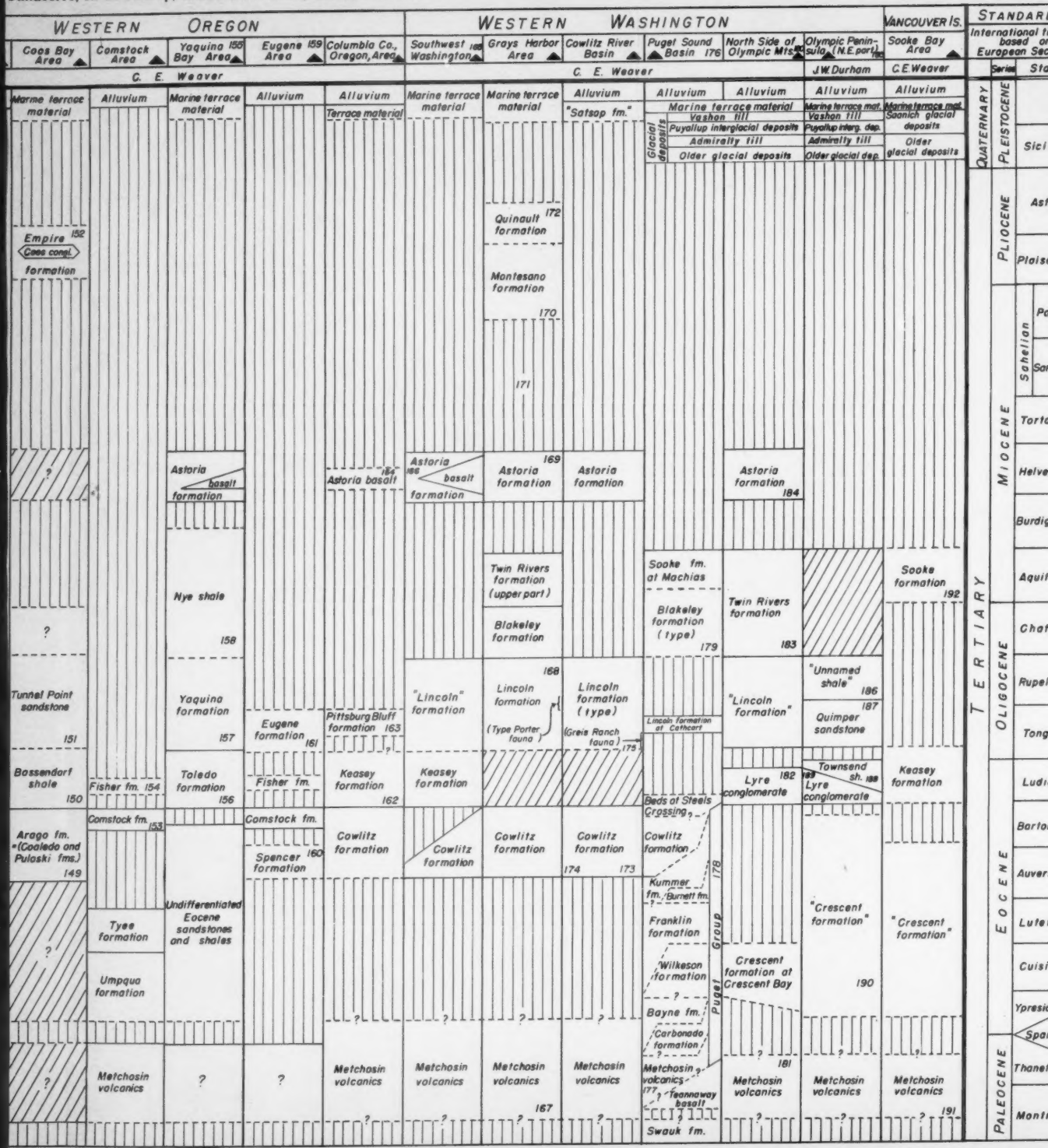
volca

S OF WESTERN NORTH AMERICA

Thomas W. Dibblee, Jr., Wyatt Durham, Glenn C. Ferguson,
Taliaferro, R. R. Thorup, Elizabeth Watson, and R. T. White.



Prepared under the auspices of the Committee on Stratigraphy of the National Research Council, Carl O. Dunbar, *Chairman*.

STANDARDS FOR CENOZOIC CORRELATION ON PACIFIC COAST OF NORTH AMERICA

International time units based on European Section 3			Classification used by Clark, Durham, Grant, Putnam, Taliaferro and Weaver 1		Classification used by Beck, Carlson, Dibblee, Ferguson, Forest, Hill, Kelley, R.M. Kleinpell, W.D. Kleinpell, Marks, Schenck, Tharup, Watson and White 2				
Series	Stage		Stages or formations	Zones based largely on metazoans 6	Series 9	European Stages 3	California Stages		Zones based on foraminifera 8
QUATERNARY	PLEISTOCENE		Terrace material		PLEISTOCENE		"A" (unnamed) 4	PLEISTOCENE	San Joaquin Valley Zones used by Ferguson & Gudmundsen; Los Angeles Basin Zones used by Wissler 7 13
		Sicilian	Tulare				"B" (unnamed)		No forams present; "Elphidium crispum"
	PLIOCENE	Astian	San Joaquin clay	Pecten coalingensis	"PLIO-PLEISTOCENE"		"A" (unnamed)		Eponides sp. "A"; Uvigerina aff. tenuistriata; Cibicides mckannai; Gyroidina altiformis
			Etchegoin	Turritella vanvleeki			"B" (unnamed)		Eponides sp. "B"; Uvigerina peregrina
		Plaisancian	Jacalitos	Astrodapsis peltoides	PLIOCENE	Plaisancian	"C" (unnamed)		Eponides exigua; Bulimina subacuminata
				Astrodapsis antiselli					Nonionella cushmani; Plectofrondicularia californica
		Sahelian: Pontian			"MIO-PLIOCENE"	Pontian			Karreriella milleri
			Neroly	Astrodapsis tumidus					Liebusella pliocenica
		Sahelian: Sarmatian	Cierbo	Echinarachnius gabbi		Sarmatian	Delmontian	U.	Bolivina obliqua
	MIOCENE							L.	Bolivina hughesi; Bulimina uvigerinaformis
		Tortonian	"Briones" 14	Astrodapsis brewerianus		Tortonian	Mohnian	U.	Bolivina modeloensis
					MIOCENE			L.	
		Helvetian	"Temblor"	Echinarachnius merriami		Helvetian	Luisian	U.	Siphogenerina collami; Siphogenerina nuciformis
				Pecten andersoni barkerianus				L.	Siphogenerina reedi; Siphogenerina branneri; Siphogenerina hughesi
		Burdigalian	"Vaqueros"	Turritella inezana santana		Burdigalian	Relizian	U.	
				Turritella inezana ss.	"OLIGO-MIOCENE"	Aquitanian	Saucesian	U.	Uvigerinella obesa
						Chattian		L.	Plectofrondicularia miocenica; Siphogenerina transversa
	OLIGOCENE					Rupelian 12	Zemorrian	U.	Uvigerinella sparsicostata
								L.	Uvigerina gallowayi
		Aquitanian	"Blakeley"	Echinophora apta	OLIGOCENE	12			
		Chattian		Echinophora rex		Tongrian	Refugian	U.	Zones unnamed
		Rupelian	"Lincoln"	Turritella porterensis					
				Turritella n. sp.					
		Tongrian		Malopophorus gabbi					
				Malopophorus stephensoni		11			
		Ludian	Keasey	Turcicula columbiana	"EO-OLIGOCENE"	Ludian		L.	"Uvigerina cocoaensis"
	EOCENE	Bartonian	"Tejon"	Turritella olequahensis	EOCENE	Bartonian	Unnamed	U.	Plectofrondicularia jenkinsi "A-1" 5
				Turritella sargenti					
		Auversian		Turritella uvasana		Auversian		M.	"Uvigerina churchi" "A-2"
			Transition beds"	Turritella applini				L.	"Planulina pseudowuellerstorfi" "A-3"
		Lutetian	"Domengine"	Turritella lawsoni		Lutetian	Unnamed	U.	"Amphimorphina californica" "B-1A"
								L.	"Cibicides coalingensis" "B-1"
		Cuisian	"Capay"	Galeodea susanae		Cuisian	Unnamed	U.	"Marginulina mexicana var. B" "B-2"
								M.	"Marginulina mexicana var. C" "B-3"
								L.	Pseudouvigerina wilcoxensis "B-4"
		Ypresian		Turritella andersoni		Ypresian	Unnamed		"Bolivina applinae" "C" zone
		Sparnacian 10				Sparnacian 10			
	PALEOCENE	Thanetian	"Meganos"	Turritella meganosensis	PALEOCENE	Thanetian	Unnamed		"Gümbelina globulosa" "D" zone
		Montian	"Martinez"	Turritella pachecoensis		Montian			"Marginulina subaculeata" "E" zone

TERTIARY

13 Zones not defined as biostratigraphic units

13 Zones not defined as biostratigraphic units

dikes. Pillow structures and occasional interbedded shales with marine fossils indicate accumulation on the sea floor.

192. The Sooke formation is exposed in places along the southeast coast of Vancouver Island and rests unconformably on the Metchosin volcanics. The type section lies in a syncline between Muir and Kirby creeks at Sooke Bay where it is approximately 1600 feet thick. The marine molluscan faunas suggest a correlation with the upper half of the Twin Rivers formation on the south side of the Strait of Juan de Fuca.

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UNIVERSITY OF WASHINGTON, SEATTLE, WASHINGTON.

MANUSCRIPT RECEIVED BY THE SECRETARY OF THE SOCIETY, NOVEMBER 1, 1943.

FIGURE 1. EASTERN END OF THE RHYOLITE
Showing fringing basal cliffs of gray lava under dark obsidian-rich layer surmounted by gray lava and pumice. Looking northwest.

FIGURE 2. FLAT FLOW LAYERS IN GRAY LAVA
In basal cliffs shown in Figure 1. Looking northwest.

FIGURE 3. FLAT FLOW LAYERS ON STEEP ONES
Probably caused by flow of lava into explosion pit. Southern edge of rhyolite. Looking north.

FIGURE 4. PUMICE DIKE
Cutting across steeply dipping flow layers and sending apophyses parallel to those layers. Dark inclusions in pumice conform to orientation of flow layers. Southern edge of rhyolite. Looking north. Width about 1 foot.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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PL. 1

DETAILS IN RHYOLITE NEAR BIG PINE, CALIFORNIA

RHYOLITE NEAR BIG PINE, CALIFORNIA

BY EVANS B. MAYO

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ABSTRACT

The basaltic field, localized in an area of structural intersections, south of Big Pine, California contains a single mass of rhyolite, shown by form and internal structure to have been erupted in place. Remelting of the first-congealed obsidian, exsolution of gases, and the resulting gas-inflation of the lava, were important factors in determining the form of the rhyolite.

INTRODUCTION AND ACKNOWLEDGMENTS

A few miles south of Big Pine, in Owens Valley, California, there is a volcanic field remarkable for its well-preserved basaltic cinder cones and flows. It is surprising to find in this basic center a single rhyolitic mass. Concerning this rhyolite, Knopf (1918, p. 73) wrote:

> "The massive rhyolites form part of a small group of rhyolite hills that project through the alluvial apron of the Sierra Nevada 8 miles south of Big Pine at the junction of Fuller and Red Mountain creeks. In the lowermost parts of these hills a flow of black, somewhat dull obsidian is shown; it grades upward into a gray variety, which is markedly flow-banded and contains lithophysae; and above this are bands of flow breccia. The summits of the hills are covered with fragmental pumice and volcanic dust. The flow structure dips gently west and northwest on the east side and steeply west on the west side of the hills. The hills appear to be an erosion remnant of a formerly more extensive volcanic formation."

In the fall of 1936, while making a structural reconnaissance of the eastern front of the Sierra Nevada, the writer noted that the internal structure of the lava presented analogies in miniature to the neighboring mountain structures. The localization of the volcanic field, and of the rhyolite itself, offered problems of some difficulty. Two weeks were spent in mapping the rhyolite in 1936, and the locality was revisited in 1937, 1938, and 1939. Reconnaissance studies in 1939, in the Inyo Range, east of Owens Valley, threw some light on the localization of the volcanic field.

The writer is grateful for the grant from the Penrose Bequest of The Geological Society of America, which enabled him to study the structure of the Sierra Nevada front, including the area of the Big Pine volcanic field (Mayo, 1941, p. 1064–1067).

GEOLOGICAL SETTING

CRYSTALLINE ROCKS

The crystalline rocks of Sierra Nevada front and foothills in this area (Fig. 1) are various granites divided by lenses and streamers of marble and schist. The granites are thought to be Upper Jurassic; a few poor, scattered remnants of fossils suggest

that the metamorphic rocks are Paleozoic. In the Inyo Range (Fig. 1, northeast corner) the rocks are intensely deformed Paleozoic sediments.

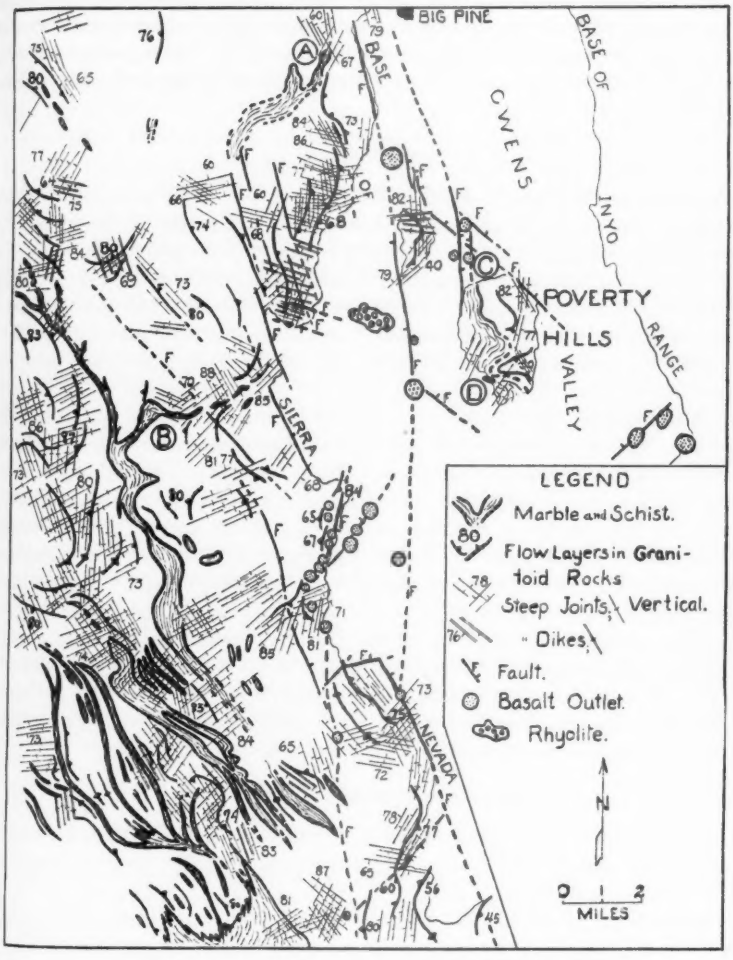

FIGURE 1.—*Structural map of the surroundings of the rhyolite*

PATTERN OF SCHIST REMNANTS AND GRANITE STRUCTURE

The regional trend of metamorphosed remnants and of the oldest planar structure (flow layers) in the granites is about N. 30°W. There are many local exceptions, but the deviation of greatest present interest is shown in the northern and western parts of Figure 1, where schist remnants and planar elements of the granite form an arc (AB), convex southeastward. Near B northeast-trending metamorphics that help to

define the southern border of this arc meet, at an acute angle, the longest northwest-trending schist streamer. The curve of the arc is reflected outward by structural trends in and southwest of the Poverty Hills. Overthrusts with outward movements toward the periphery of this curve are exposed near A and B and are thought to exist also between these points. Future studies may show that AB is part of a broad, arcuate belt of thrusts that included the Poverty Hills and originated at the time of emplacement of the granites.

JOINT PATTERN

All joints shown on Figure 1 dip more steeply than 59°. These steep fractures are thought to have originated contemporaneously with the granites, because many of the joints carry dikes that are related petrographically to the granites.

Throughout large areas in the Sierra Nevada (Mayo, 1941, p. 1051–1053) many of the steep joints conform to one of four directions, as follows: (1) Many joints trend N. 20°–45° W. and are complementary to (2) numerous steep fractures that trend N. 50°–70°E.; (3) local joint swarms are oriented nearly N.-S., and these are traversed by (4) fractures oriented N. 60°W. to E.-W.

In the vicinity of the rhyolite, the joints of direction 1 follow the crest of the Sierra Nevada (Fig. 1, southwestern part) and are traversed nearly at right angles by joints of direction 2, which is well represented by the joints west and south of B. The mapping did not disclose the joints of direction 3 very plainly, but a few nearly north-south fractures appear near the southern edge of the map. There is a swarm of them southwest of B, and a few more are shown north of the rhyolite. Direction 4 is represented by the dike swarm 1 mile west of the rhyolite and by many joints a few miles farther north.

Locally the trend of a given set of fractures varies somewhat, and the angular relations among the several sets vary also. Local bends in the flow layers, and in the intrusive contacts, may cause corresponding changes in the orientations of the joints. For example, the arc AB is followed by joints that reproduce fairly accurately its curve. Complementary, transverse fractures fan out southeastward.

FAULTS RELATED TO TERTIARY-PLEISTOCENE UPLIFTS

The pattern of faults, related to the final uplifts of the Sierra Nevada, roughly resembles the joint pattern. This resemblance could probably be strengthened by further detailed mapping.

Some of the faults strike N. 20°–45° W. and locally control the trend of the western side of Owens Valley. These fractures are obviously related to joint direction 1.

A few known faults trend northeasterly (Fig. 1, southern half) and are related to joint direction 2; possibly other northeasterly fualts occur in this area but were not mapped. These fractures cause local re-entrants in the Sierra Nevada front. In the Inyo Range, beyond the area shown in Figure 1, northeasterly faults are very prominent and are paralleled by local folds in the Paleozoic rocks.

Some of the longest faults change trend from N. 20° W. nearly N.-S. The local trend of Owens Valley south of Big Pine clearly indicates a structural control inherited from joint direction 3.

Certain faults, as near C and D, strike N. 50–60° W. and seem to be related to joint direction 4. These faults cross Owens Valley diagonally and strongly affect the topography in the Inyo Range. They are repressed in the Sierra Nevada, but west of the rhyolite are a few N. 70° W. faults that are plainly renewals along joint direction 4. There appear to be no Tertiary or Pleistocene faults that follow the arc AB, but more detailed mapping might reveal some. The fault pattern east of this arc roughly suggests the curve.

The dips of these presumably normal faults are not known. Scarplets, along the fault traces, slope at the angle of repose of the unconsolidated materials which are traversed by the faults, but the actual dips of the fault planes may be much steeper. Because the faults appear to follow the pattern of older, steep joints, it is thought that the faults dip as steeply as the joints (60°–90°). However, there are gently dipping Tertiary or Pleistocene faults in the area.

At a number of places on the eastern side of the Poverty Hills, weakly cemented shear zones, apparently small thrusts, dipping gently westward, have been exposed in road cuts. At C (at the northern end of these hills) schistose granodiorite has pushed out westward over unconsolidated rubble (Mayo, 1941, p. 1062. Therefore, late Tertiary or Pleistocene movement was here accompanied by intense local compression. Perhaps old thrusts, deployed along and beyond the arc AB, and related in origin to the emplacement of the granite, were rejuvenated. Most of the volcanic eruptions are where this supposed thrust belt was broken along steep, intersecting faults.

Most of the basaltic cinder cones lie on or near known faults. For example, Crater Mountain, 3 miles southeast of A, and Red Mountain, 1½ miles west of D, are on the same north-south fault. Many cones are arranged along a north-south or a northeasterly fault at the base of the Sierra Nevada 5 miles east-southeast of B. Two cinder cones are on a northeasterly fault at the base of the Inyo Range, southeast of the Poverty Hills. A few cinder cones are on fault intersections such as Red Mountain and some small cones north of C. One elliptical basaltic pipe (D) is on no known fault, but elongated parallel to joint and fault direction 4.

RHYOLITE

MORPHOLOGY

The rhyolite mass approximately 4 miles west of "Poverty Hills" on Figure 1 (Figs. 2, 8) is roughly oval in plan. This oval is marred by two buttresses, or lobes (Fig. 2, N and S), one on the northwest, the other on the southeast. The eastern and western ends, also, are lobelike. The longest axis is approximately 4800 feet and trends about N. 70° W.; the average width is 1800 feet. The mass appears to be about 250 feet thick and resembles an irregular shield with broad, gently undulating summit. It is tilted eastward about 4°, because it rests on the piedmont slope of the Sierra Nevada. About 100 yards beyond the western end is an isolated, northwest-trending rhyolite ridge, about 30 feet high and perhaps 600 feet long.

The chief irregularities in the broad summit of the main mass are a few small, marginal valleys; a low, craggy, west-northwest-trending ridge near the northeastern edge; and two domelike mounds (Fig. 2, 1 and 2) that rise 30 or 40 feet above the

general summit level. The highest mound (Fig. 2, No. 2) is in the western part of the rhyolite within the 5300-foot contour; the other (Fig. 2, No. 1) near the eastern end, is encircled by the 5200-foot contour (Fig. 8). The surface is incompletely covered by a thin layer of sand, pumice fragments, obsidian flakes, and round obsidian pellets. A few cobbles of granitic rocks were found in this debris.

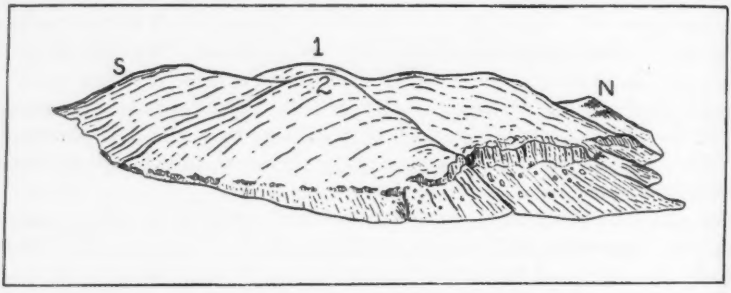

FIGURE 2.—*Rhyolite from the summit of the Poverty Hills*

N is the northwestern buttress, S the southeastern buttress; 1 and 2 are the summit mounds. Eastern lobe faces the observer. (From a photograph.)

Along the northern, eastern, and southeastern sides there are cliffs, 5 to 30 feet or more high. On the northern and eastern sides an apron of rhyolite talus exists below the cliffs. The western, and most of the southern, edges slope more gradually, and coarse fanglomerate of the Sierra Nevada piedmont has locally piled against the base of the rhyolite.

The form of the rhyolite—the shield with domelike summit mounds and buttresses that resemble stubby flows—strongly suggests a moderately viscous extrusion that spread little beyond the orifice. Dacitic flows, known to have moved little beyond their places of eruption, and with similar forms, have been described from Crater Lake, Oregon (Allen, 1936). At the start of the investigation I assumed because of this similarity of forms, and the lack of evidence that the rhyolite was modified greatly by erosion that the rhyolite covers the place of eruption. This assumption was progressively strengthened as the study advanced.

VARIETIES

General statement.—The rhyolite is everywhere highly vitreous. The visible crystalline material does not seem to exceed 2 or 3 per cent of the rock. The glass, however, is far from uniform; it varies strikingly in porosity and therefore in appearance.

Three principal varieties—dense black obsidian, gray lava, and pumice—have been recognized. The gray lava owes its distinctive color to millions of minute gas pores, and by increase in the sizes of these pores it may grade into pumice. The irregular fracturing, during movement, of any of these varieties has made various flow breccias. In the pumice, explosion breccias locally resulted from the violent discharge of gases.

Obsidian.—An attempt has been made (Fig. 8) to generalize the distribution of the

FIGURE 3.—*Stages of remelting and flow breccia*

(A) Partially remelted, flow-banded obsidian. From southern edge of rhyolite.
(B) Final stage in remelting of obsidian. Top of basal cliffs at eastern end of the rhyolite. A few of the smaller obsidian bands were softened and drawn into schlieren.
(C) Flow breccia with sporadic fragments. In the pumiceous matrix are spherulites, angular to subangular fragments of gray lava and rounded fragments of obsidian. Largest gray lava fragment contains several obsidian inclusions. From above the obsidian-rich zone, near the eastern end of the rhyolite.

obsidian, and it can be seen that the dark glass occurs, as many small blocks, lenses, and lesser inclusions. Some of the obsidian masses may be several yards across, but from this the size ranges to barely visible crumbs. Along the northeastern, eastern, and southeastern sides of the rhyolite the many lenses and lesser inclusions give the lower parts of the slopes a dark tinge (Pl. 1, fig. 1), which is probably responsible for Knopf's statement (1918, p. 73) that a flow of black obsidian exists in the lowermost parts of these hills. Most of the obsidian is embedded in gray lava; inclusions of the black glass are small and comparatively rare in the pumice.

Gray lava.—This dominant variety is usually pearl gray or ash gray and dense looking wherever its many gas pores are too small to be seen without a hand lens. The rock is everywhere divided into layers of contrasting colors (Pl. 1, fig. 2). In the lightest layers the number of pores is greatest and their averge size smallest; in the dark layers the number of pores is relatively small.

The gray lava makes up the basal cliffs fringing the eastern end of the rhyolite and forms the matrix in the dark, obsidian-rich zone above these cliffs. The eastern and western slopes are composed mostly of gray lava, locally interlayered or interlensed with obsidian, and locally forming one of the constituents of flow breccias. This gray rock is exposed at many places on the broad, undulating summit of the rhyolite, and it makes up the small, isolated ridge west of the main body.

Pumice.—The pumice is appreciably lighter in weight than the gray lava and obviously frothy. It occurs not only as the most porous bands in the gray lava but also as small, irregular, or dikelike bodies (Pl. 1, fig. 4) and as larger masses. Pumice is the most abundant rock in the western lobe and in the two summit mounds. In some outcrops, especially in the summit mounds, the pumice was brecciated. The breccia fragments vary in porosity and lie in a frothy matrix. From the shapes of the outcrops, some of these pumice breccias appear to be pipe- or funnel-shaped bodies. The material in these pipes is somewhat oxidized.

STRUCTURAL RELATIONS[1]

Flow structure of the obsidian.—Most pieces of the dense obsidian appear quite structureless except where weathering tends to bring out a fine lamination, but all chips suitably oriented and thin enough to be translucent show many closely packed strictly parallel, alternating, light and dark laminae. The dark laminae are crowded with crystallites. It is not known whether a linear structure was developed within these thin layers.

The fine, laminated structure must constitute the earliest available record of motion in the rhyolite because the field relations show that the obsidian is the oldest type of rhyolite. This motion was an evenly distributed, very penetrative, differential, viscous flow. In consequence of this flow, which may have occurred mainly within the conduit at uniformly high temperature and pressure, the magma had begun to segregate into fine, alternating crystallite-rich and crystallite-poor layers.

In most outcrops this fine, but usually invisible, banding is paralleled by coarser gray or white layers of variable thickness. These light-colored layers, which impart

[1] A block diagram of the rhyolite has been published (Mayo, 1941, p. 1066). The obsidian-rich layer, above the eastern basal cliffs, was not shown on the block diagram.

to the obsidian a readily visible structure (Pl. 1, fig. 4), owe their contrasting color to the presence of minute gas pores. The shade of gray depends upon the size and abundance of the pores. A few large pores characterize certain layers, or lenses, of scoriaceous obsidian; many minute pores are light gray, and the frothiest fine-grained layers are white. Many of the pores are elongated lenses or tubes, and their mutual parallelism lends to the gray layers a fibrous, linear structure. These flow lines always lie within the layers, and the pitches of the lines may or may not coincide with the dips of the layers.

The interlayering, or interlensing, of obsidian and gray material appears to have been a further and coarser phase of the segregation that resulted in the fine lamination of the obsidian. The coarser layering in gray was accompanied by some exsolution of dissolved gases and probably by the transfer of differential motion from the many fine, closely packed laminae to fewer favored, more widely spaced planes. According to Balk (1937, p. 161–162) it seems that a similar transfer of motion from many to few planes has been inferred by H. Philipp from observations on the structure of lavas and artificial glass residues. In his paper on the Adirondack anorthosite Balk (1931, p. 361–369) discussed the transfer of motion from many, closely spaced flow planes to somewhat later, more restricted shear zones. In the obsidian also the gray layers are probably somewhat later than the closely packed laminae. It seems that motion in the gray layers occurred at, or near, the surface where reduced pressure began to favor exsolution of gases.

Structural relations between obsidian and gray lava.—The relative amounts of obsidian and gray lava (Fig. 8) vary from place to place. At one extreme is dense obsidian with a few thin, gray layers; at the other is gray lava with scattered, small inclusions of obsidian.

The obsidian shows evidence of remelting. Smooth, shiny surfaces and even sharply angular pieces have a partially remelted appearance. A general survey of the rhyolite reveals many stages in remelting; a few of these will be noted.

Early stages in the conversion of obsidian to gray lava are best shown in the large, shattered obsidian blocks on the southern edge of the rhyolite. The initial stage, obsidian with thin, parallel gray layers, apparently with no evidence of remelting, occurs where the flow structure was not folded (Pl. 1, fig. 4, on either side of pumice dike), and later stages (Fig. 3A) were developed in connection with the flexing of brittle, or highly viscous, obsidian plates that were separated by more fluent gray layers. In response to the local stresses, many cracks formed across the obsidian. Subsequently, either the gray lava was inserted into these cracks, or the obsidian along the cracks was remelted and inflated. In either case, the obsidian layers are now divided by crosscutting gray material into many various-sized fragments, which still show the original layered structure. Some remelting must have taken place as is indicated by the shapes of these fragments. Some of them remain subangular, others are partly rounded, and a few of them resemble gum drops.

Nearly spherical inclusions of obsidian range in size from golf balls to bird shot and are common throughout the gray lava. Many of these, freed from their matrix by disintegration, lie about on the broad summit of the rhyolite. Their subspherical shapes were obviously acquired by solution or remelting.

In final stages of the remelting (Fig. 3B) the obsidian was reduced to scattered clusters or chains of small, black beads. Some of the smallest of these, softened by immersion in the hot gray lava, have been drawn out, by motion of the gray matrix, into delicate, lacelike schlieren. At many places in the basal cliffs at the eastern end of the rhyolite, close inspection of the gray lava showed many tiny, beadlike pearl-gray bodies. These are assumed to be the final remnants of obsidian beads that were neither completely remelted nor drawn into schlieren.

These observations indicate that undoubtedly a great deal of obsidian has been converted into gray lava by remelting and inflation. They do not, however, preclude the possibility that some of the gray lava represents fresh increments of hot magma that invaded the congealing obsidian. Indeed, either fresh magma or floods of hot gas must have supplied the heat to remelt the obsidian. The gray layers are

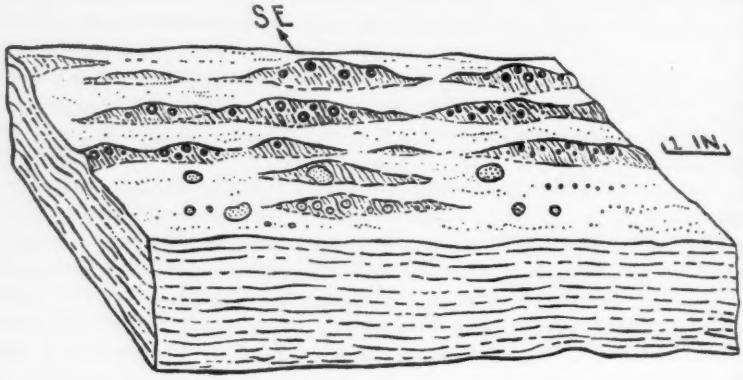

FIGURE 4.—*Spherulites and obsidian pellets*

Arranged in linear rows parallel to the crests of ripplelike folds in gray lava. Summit of eastern cliffs of rhyolite

favored shear planes in the obsidian and may have been the principal channels for this heat. Owing to the brittleness of the obsidian, many additional, crosscutting channels were formed whereby the isolated obsidian blocks could be attacked from every side. As this attack progressed, it converted the formerly rigid areas of obsidian into mobile masses with many small, glassy inclusions. Most of the primary structure of the gray lava appears to belong to this second stage of flow.

Flow structure of the gray lava.—The gray lava also is divided by flow layers (Pl. 1, fig. 2) within which the gas pores or other elongated elements are arranged into flow lines. Perhaps the simplest arrangements of these flow structures are in the eastern, basal cliffs where the dips of the layers are very gentle and only few outcrops reveal signs of folding. Locally small recumbent folds are preserved. In this part of the gray lava the pitch of the flow lines rarely coincides with the dip of the flow layers, and frequently the lineaments are horizontal, parallel with the strikes of the layers.

At some places the horizontal lineation consists not only of the parallel arrangement of stretched gas pores and other linear objects, but of rows of spherulites and obsidian pellets (Fig. 4), most of which are in the crests of small, ripple-like folds on the surfaces of the flow layers. The rows of spherulites and obsidian pellets were arranged athwart the prevailing motion. Accordingly, the once overlying layer (Fig. 4) moved southeastward with reference to the block.

The generally simple flow structure at the eastern end of the rhyolite probably means that here the spreading gray lava was fairly mobile and no great differences in viscosity existed among the various layers. Possibly, however, the flow structure

here was once intricately folded and, while the lava could still flow, these complications were "ironed out" under the weight of material that was accumulating above. In other parts of the rhyolite most of the flow layers in the gray lava are intricately

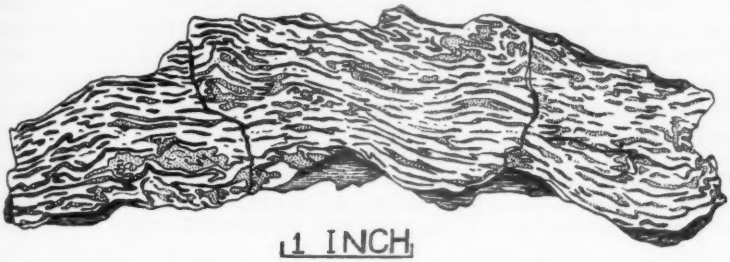

FIGURE 5.—*Flowage folds in thin-layered gray lava*

Specimen from the southern edge of the rhyolite.

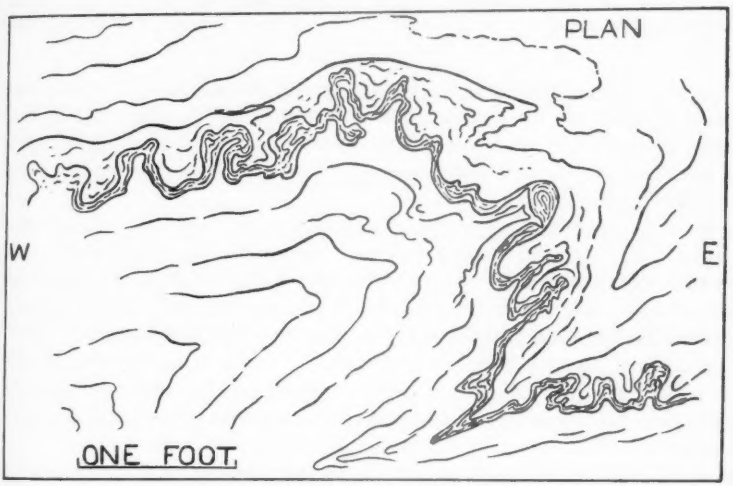

FIGURE 6.—*Flowage folds in gray lava*

From summit of northwestern buttress.

folded. It is thought that these flowage folds are the result of viscosity differences among adjacent layers (Knopf and Ingerson, 1938, p. 132).

Where the flow layers were thinnest, the folds are very small (Fig. 5). The less mobile layers have been disrupted, or pulled apart, into variously-bent lenses of many shapes and sizes. The little folds are sharpy overturned toward the direction of flow.

Where the flow layers were thicker, and the viscosity differences among them were marked, the folds were larger. In one case (Fig. 6) a prong, advancing from a sharp fold in a highly viscous layer, had nearly dissected a neighboring fluent layer. On several sharp flexures bulblike protrusions of fluent lava were formed, which seem to have pushed like tiny intrusive salt domes into the adjacent,

less fluent material. Although a direct comparison is not possible, folds like the one shown in Figure 6 are similar in certain respects to flowage folds found in the metamorphic rocks of the Sierra Nevada, where argillaceous beds alternated with calcareous ones (Mayo, 1941, p. 1017–1018).

The flowage folds grade locally into brecciated rock, and it seems significant that most of the flow breccias occur along the southwestern edge of the shield, where several large, sharp folds pitch gently under the rhyolite. The areas of breccia represent places where the more brittle parts of the lava were unable to continue the intricate folding favored by the more mobile layers. Shattering of the rigid parts was the inevitable result.

The flow breccias grade from crackle breccias, in which the individual fragments are separated by narrow cracks, or by thin films of frothy material, through many beautiful intermediate stages, to breccias in which sporadic fragments, mostly gray lava, but some obsidian "float" in pumiceous or pasty matrices.

It is not known whether, in the formation of the breccias of sporadic fragments, there was a second period of remelting, during which the gray lava fragments were remelted and further inflated. Opposed to this possibility are the generally angular shapes of the gray lava fragments. No rounded ones were noted. In some way, however, rounded inclusions of obsidian may have been freed from the gray lava; they now occur with spherulites in the pumiceous matrices of these flow breccias (Fig. 3C).

Structural relations between obsidian-gray lava and the pumice.—The most porous layers in the gray lava are pumice. The boundary between a pumiceous layer and the finer-grained gray lava is not definite. Structurally, the layers of pumice and gray lava are perfectly concordant, and obviously the pumice was merely the gas-richer part of the gray lava.

A few thin, concordant pumice layers have very sharp, definite contacts with the gray lava (Fig. 7). In the example illustrated, the obsidian inclusions in the pumice layer are larger than those in the surrounding gray lava. The two interpretations of this phenomenon are: (1) Fluent, gas-rich lava, charged with obsidian inclusions, may have been injected along the foliation of the gray lava; (2) the pumice layer, with its dark inclusions, may result from the partial remelting and inflation of an obsidian layer in the gray lava. The writer is inclined, because of the relatively large size of the inclusions in the pumice, to favor the second interpretation, although data are not conclusive.

Pumice forms the matrices of some of the flow breccias. In most of these matrices, linear structure only is developed and is not parallel to the internal structure of the gray lava fragments. At many places, indeed, although linear elements (drawn out gas pores) are present, their longest axes are not subparallel. At such places the structure of the pumiceous matrix either conforms to a very complicated pattern or is without order. The structure appears to be simplest in the matrices of the breccias of sporadic fragments and more irregular where the fragments are closer together. It seems as though chaotic masses of rubble were in process of being organized again into orderly movement patterns. This process apparently culminated, during the latest stages of flow, in the rise of large, frothy masses that formed the summit mounds and much of the western lobe of the rhyolite.

Some dikelike bodies of pumice traverse the steeply dipping layers of obsidian and

gray lava (Pl. 1, fig. 4) and follow the radial joints (Fig. 8) in the rhyolite. The dikes are connected with irregular bodies of pumice that are conformable with the structure of their surroundings. Even in the crosscutting, dikelike extensions, obsidian inclusions in the pumice are oriented with their longest axes parallel to the flow layers of the obsidian "wall rock". Obviously, the attitudes of the dike walls have had no

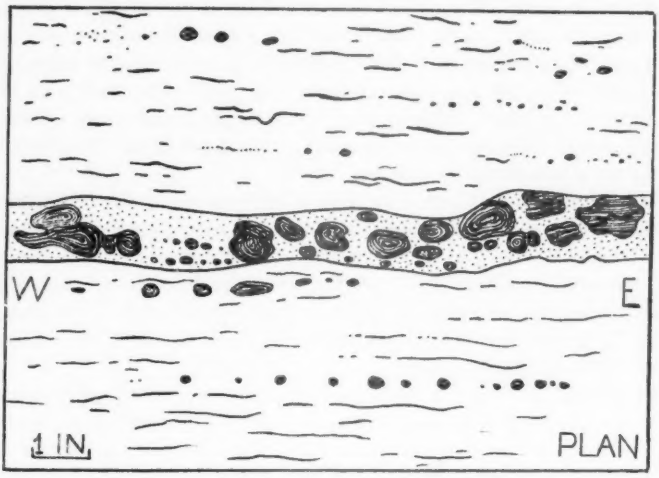

FIGURE 7.—*Pumice layers with obsidian pellets*

Summit of northwestern lobe of rhyolite.

orienting effect on the obsidian inclusions, and the pumice dikes apparently result from the remelting and inflation of obsidian along the radial joints. If this interpretation is correct, the obsidian inclusions are undisturbed relics that escaped complete remelting.

Balk (1937, p. 52–54) has discussed dikes with disconformable flow structures. In some cases, where the linear flow structures of dikes are perpendicular to the dike walls, the strikes of these linear structures can be correlated with a direction of regional crustal distesion. As will be noted later, the radial joints of the rhyolite are tension joints, formed in response to the stretching of the periphery of the spreading lava. Consequently, the walls of the pumice dikes may have been pulled apart as frothy, remelted obsidian, or injections of fresh, gas-rich magma, or both, expanded to fill the resulting space. In this event the stretching of the frothy material perpendicularly to the dike walls may have oriented the residual obsidian inclusions. There is no strong, horizontal, linear arrangement of gas pores in the pumice dikes, however, and for this reason it is thought that here the orientation of the inclusions is an inherited, undisturbed relic of "wall rock" structure.

At one place only was pumice with faint, elusive, gently inclined flow layers, and rather abundant, subangular inclusions of obsidian, seen to rest disconformably on shattered obsidian with steep flow layers (Pl. 1, fig. 3). Unfortunately, the exposures at this place were not extensive enough to reveal clearly the explanation of this disconformity, but it is thought that there a pit had been blasted, by a destructive surface explosion, out of the rigid obsidian and that the pumice had welled up to fill, and possibly overflow, the resulting depression.

STRUCTURAL PATTERN

General relations.—Most of the measurements of dips and strikes of flow layers, pitches and strikes of flow lines, and attitudes of joints have been plotted on the map (Fig. 8). From this assemblage of measurements the following relations emerge:

(1) Except locally, along the margins and especially at the eastern end, most dips of flow layers are steep. This would seem surprising if the rhyolite were part of a formerly extensive flow. In that case it would be necessary to suppose that the lava had advanced over a surface that offered such great, or such variable, resistance that the flow layers were thrown into steep-flanked folds. If, on the other hand, the lava were erupted at this place, the steep flow layers, locally accompanied by steep flow lines, are logically explained by nearly vertical rise of the lava. Moreover, gentle dips along the edges would be expected.

(2) Flow planes near the edges of the rhyolite conform remarkably with the present outlines of the mass. In other words, the structural pattern fits the present size and shape of the shield. Only along the southwestern margin does the outline of the rhyolite truncate the internal structure; the reason for this will be discussed below. Even the small, detached mass off the western end appears to be a complete structural unit. By what remarkable coincidence could this be true if the rhyolite were the erosion remnant of a lava flow?

(3) A system of steep joints shows a roughly radial arrangement with respect to the center of the mass. Most of these joints are restricted to marginal portions of the rhyolite, and, further, to the northern, eastern, and southeastern margins. These must be tension joints, related to the local spreading of the viscous lava. They, like the flow layers, are disposed with close regard for the present size and shape of the rhyolite. They indicate by their distribution those places where the nearly rigid lava had the greatest tendency to spread.

Because of these general relations it seems fair that the following description of the structural pattern proceed on the assumption that the rhyolite was erupted at this place.

Structures around the eastern summit mound.—The eastern summit mound is composed of pumice, so crumbly that its internal structure could not be mapped. The domelike shape and its position on the eastern lobe suggest that the mound is directly above a local outlet. If this is true, the first materials erupted here have been obsidian and gray lava, and these were followed by pumice, which forms the core.

The obsidian and gray lava, as shown by the patterns of flow structures and tension joints, spread northward, eastward, and southward. The close association of steeply and gently dipping flow layers along the margin south of the eastern summit mound indicates that here the spreading lava curled under at the edge, forming "rollers" or recumbent folds in the flow layers. Two directions of lineation are developed here: (1) One direction, more commonly observed, is almost directly down the dips of the flow layers. It strikes approximately at right angles to the edge of the lava and coincides with the local direction of flow. (2) The other is essentially parallel to the edge of the lava and is probably parallel to the nearly horizontal axes of recumbent folds. This lineation lies athwart the local direction of flow.

The flat flow layers and associated flow lines at the end of the eastern lobe have

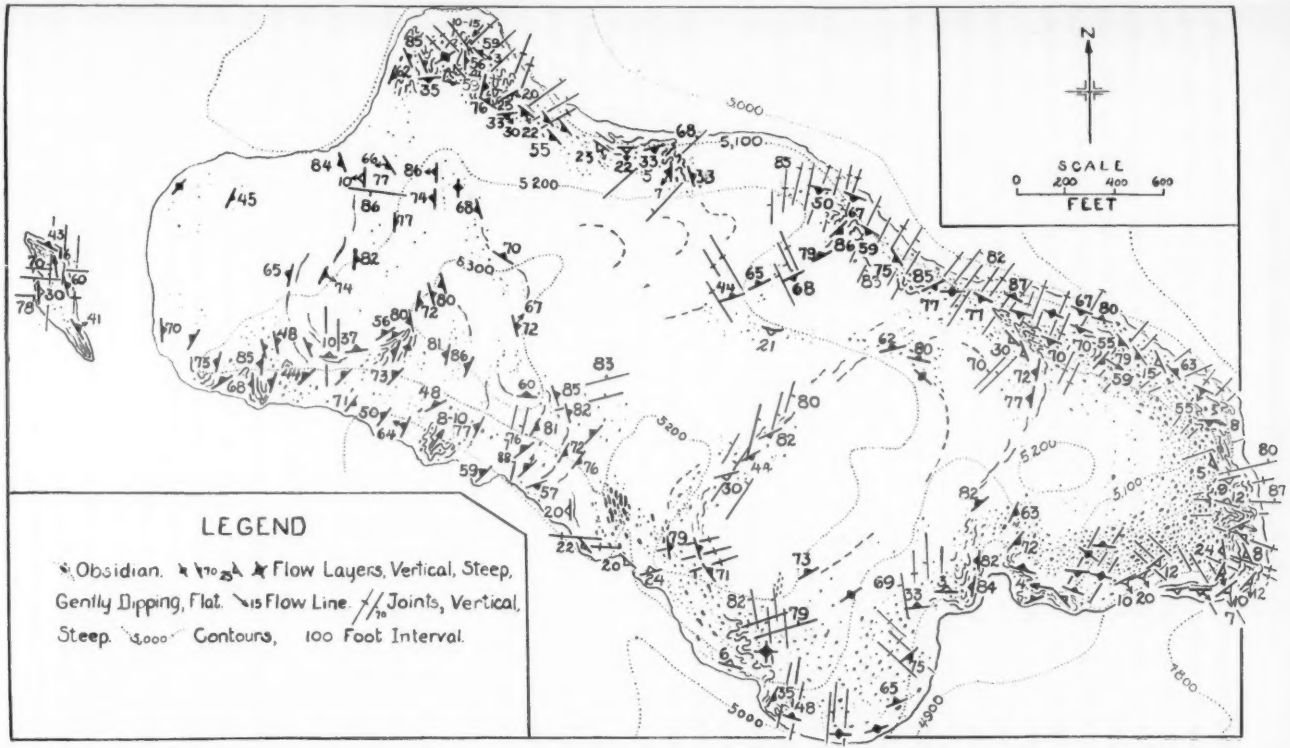

FIGURE 8.—*Structural and topographic map of the rhyolite*

been described in the section on flow structure of the gray lava. At the southeastern corner the eastwardly spreading lava tended to turn southward, as indicated by the southward-pitching flow lines.

Funnel west of the eastern summit mound.—A few hundred feet west of the eastern summit mound, readings on the flow layers partially outline an ellipse. The longer axis of this ellipse trends N. 45° E. and has a length of 1500 feet; the shorter axis may be 700 feet long. Most of the steep dips are inclined inward around the edge of this ellipse. The structure is, therefore, a steep funnel.

Judged from the surface rubble, the core of this funnel is pumice, and this core, again, must lie above an outlet and be the last material erupted. From this center gray lava and obsidian spread, mostly southward, to form the southeastern buttress. It is thought that the vertical flow layers, seen at the edge of this buttress, curl under to parallel the surface over which the flow advanced. The tension joints in the buttress are arranged in a crude fan which opens southward.

At the northeastern end of the funnel is the craggy, west-northwest ridge. Flow layers in this ridge are steep, and their strike is remarkably constant (about N. 70° W.). As this strike coincides with the trend of the ridge, it is thought to be a dike. The fracture, from which this dike issued, parallels regional joint direction 4. The tension joints of the rhyolite cross the dike nearly at right angles.

Structures near the western summit mound.—The flow pattern of the western summit mound is complicated. Perhaps magma, issuing from separate orifices, merged to form the intricate pattern here, or perhaps there was only one orifice with very irregular shape. West of the mound is a steep-sided synclinal structure, trending north-northeast, and closed on the south. The eastern limb of this structure, on the southwestern slope of the summit mound, is doubled sharply back, and from this sharp buckle the steep flow layers stream toward the southern edge of the rhyolite.

This synclinal structure is probably part of a very irregularly shaped funnel, formed by the upwelling of viscous lava from an orifice. The topographically highest parts of the structure are composed of pumice. At first, one is impressed with the similarity of the structural pattern to the plan of a breached crater. It seems that one side of the funnel has given away, allowing the lava to escape to the southern edge of the shield. There are, however, some serious objections to this concept.

If the lava did escape from the funnel and flow to the edge of the shield, why was no buttress or lobelike extension formed, and why do the flow layers not conform to the local outline of the rhyolite? Surely these conditions are met at other places where the evidence of lateral flow is reasonably clear. The answer could be that a lobe, outlined by flow layers, was formed but was removed by erosion. It would be strange, however, if so much erosion had occurred here, whereas other parts of the rhyolite were hardly affected. The inwardly pitching folds, along the edge of the rhyolite at this place, may offer the solution. Flow lines, following the axes of these folds, pitch gently toward the western summit mound; even where the folds are not apparent, flow lines, lying in steep flow layers, still pitch gently north-northeast. This indicates that lava, issuing from one or more north-south fissures, was crowded upward and outward at a low angle past the narrowing southern ends of the fissures. The lava probably did not spread appreciably after it reached the surface. Radial tension fractures were not found here.

In the northwestern buttress tightly squeezed folds, with axes pitching gently and converging southward, suggest the upward and outward thrust of lava beyond the narrowed-down northern end of a north-south fissure. A crude fan of tension joints and general conformity of the layers with the outline of the buttress indicate that here the lava had started to spread beyond the fissure of eruption.

Leading out from the western summit mound toward the east-northeast is a long, smooth, narrow ridge. Flow layers in gray lava are bent sharply around the eastern end of this ridge, and there is some indication that the structure of the ridge is a steep-walled syncline. The lava probably issued from an east-northeast fissure and expanded somewhat toward the surface. The western summit mound lies at the intersection of this fissure with the above-noted north-south fissures. It appears that this intersection was a locus of maximum magma supply, and above it masses of pumice were upheaved to unusual height.

The western lobe of the rhyolite could be interpreted as a flow that, issuing near the western summit mound, spread westward. If this were the case, then, judged from the present shape of the lobe, the most rapid flow of the lava was directly uphill. This could have happened, especially if the lava were confined to north and south by embankments of ash and pumice lapilli that have since been eroded. Because of the nearly north-south trends of the flow layers, the presence along the southern margin of gently northward-pitching folds, and the lack of the usual fan of tension joints, it is suggested that the western lobe was erupted essentially in place from one or several north-south fissures. Because the lobe is composed mainly of pumice, it was probably a late addition to the growing structure.

Isolated rhyolite ridge.—The structure of the little ridge of rhyolite, beyond the western end of the main mass, resembles a westwardly overturned fold. Easterly dipping flow layers along the eastern side of the ridge are steeper than those along the western side, and flow lines pitch directly down the dips of the steep layers. On the summit of the ridge, the linear elements pitch gently north-northwest, parallel to the strikes of the layers. This secondary direction of lineation would seem to indicate the active elongation of the lava parallel to the axis of a fold. The flow layers do not arch over the ridge, however, and, if a fold ever did so close, the apex may have been destroyed by explosions. The gray lava appears to have moved obliquely upward from east-northeast to west-southwest from a source beneath the main mass of rhyolite.

Directions in the structural pattern.—The writer believes that, where the structure of a region is being mapped, certain dominant directions begin to emerge when sufficient data have accumulated from a large enough area. An example is the four regional directions of jointing. These directions appear likewise in the flow pattern of the Sierra Nevada (Mayo, 1941, p. 1049–1050) and are therefore older than the joints. The directions form a sort of framework on which the minor details of structure are hung.

In spite of having found such prominent directions in regional patterns, it was a surprise to see them emerge in a structure so small as the rhyolite. Unless inference has gone too far beyond observation, however, these directions do appear in the structural pattern and in the morphological plan of the rhyolite.

The dominant direction, even though it is not followed by a majority of the flow

layers, is about N. 70° W. This direction is followed by the longest axis of the rhyolite and by the craggy, west-northwest ridge, or dike. This is regional joint and fault direction 4, which is followed by the dike swarm 1 mile west of the rhyolite (Fig. 1) and by the longest axis of the elliptical basaltic orifice (D) east-southeast of the rhyolite.

The longest axis of the funnel west of the eastern summit mound trends about N. 45° E., and the axis of the syncline west of the western summit mound follows in part the same direction. The long, smooth ridge east-northeast of the western summit mound trends N. 80° E. None of these orientations falls within the limits previously given for joint and fault direction 2; nevertheless, it is supposed that cylinder, syncline, and smooth ridge reflect the influence of fissures that approximately followed direction 2.

The inferred fissures of eruption near the western summit mound, and in the western lobe, appear to strike between N.-S. and N. 20° E. This is regional joint direction 3.

The isolated, rhyolite ridge, beyond the western end of the main mass, is oriented about N. 25° W. Apparently direction 1, which is of first importance in the Sierra Nevada, plays a very minor role at the place of eruption of the rhyolite.

It seems that the crust beneath the rhyolite was fractured along the four regional directions of jointing and faulting; this fracture pattern was reflected, however roughly, in the flow structure of the rhyolite. Obviously, the shape of the orifice was very irregular, or the lava was erupted from a small, compact cluster of orifices. This outlet, whatever its nature, was localized where the several directions of fracturing intersected.

DISCUSSION

LOCALIZATION OF VOLCANIC FIELD AND RHYOLITE

Regional relations.—The eastern front of the southern Sierra Nevada is not characterized along its entire length by volcanic eruptions. Volcanic fields are at widely spaced nodes along this front. Beyond the southern limit of the map (Fig. 1) the nearest volcanic cluster, comparable to the field south of Big Pine, is near Little Lake, 65 miles south. Northward, it is about 15 miles to an area of scattered basaltic eruptions west of Bishop.

The author (Mayo, 1941, p. 1064–1069, 1081) noted that where the escarpment of the Sierra Nevada is fairly straight evidence of Pleistocene volcanic activity along it is lacking; but, where the escarpment becomes irregular, volcanoes appear. The intensity and duration of the volcanic activity seem to have been roughly proportional to the irregularity of the scarp, and the volcanoes tend to cluster in embayments. The volcanic fields are separated by a long interval of straight scarp or by shorter distances where salients intervene.

Where the escarpment is straight, only one direction of faulting (the northwest direction) is in control, but where the scarp is irregular other directions of faulting interfere. Where very strong faults follow directions that diverge from the general trend of the Sierra Nevada, the salients and re-entrants are largest.

The volcanoes south of Big Pine are clustered in and near a shallow, jagged re-

entrant (Fig. 1). This embayment is located where zones of structures (faults, folds, or intrusions), corresponding in trend to joint directions 2 and 4, impinge upon the northwesterly faults that bound the Sierra Nevada. From the embayment direction 2 can, with some interruptions and changes of trend, be followed across the Inyo Range and neighboring Basin Ranges for at least 80 miles beyond the Sierra Nevada. Direction 4 likewise can be traced toward the east-southeast many miles from the Sierra.

These structures of diverse trends were roughly indicated on a map (Locke *et al.* 1940, Pl. 1). On that map the Big Pine volcanoes are shown by the letters RC, from which northeasterly structures trend toward Tonopah (T), and Goldfield (G), both in Nevada; and west-northwest structures, indicated by aligned intrusions, trend toward Emigrant Wash (EW), and Towne's Pass (TP).

The intersecting faults along which the supposed thrust arc was broken down (discussed under section on Faults related to Tertiary-Pleistocene uplifts) thus appear to be the local expressions of regional features. As previously stated, it appears that, in the general area of this intersection, thrusts traveled outward from the Sierra at about the time the granitic intrusions were emplaced. In Tertiary or Pleistocene time thrusting was renewed here, and part of the thrust arc foundered, or perhaps lagged behind the general uplift of the Sierra. This apparently down-faulted area is the embayment—the site of the Big Pine volcanic field.

Theory of position.—Billingsley and Locke (1933, p. 12) found that most of the principal ore districts in the West were localized where belts of Tertiary thrusts intersected folds that involved Paleozoic and pre-Cambrian rocks. Those authors concluded:

"Under these conditions channels are opened whereby material from within the crust, hot and under high pressure, can become fluid and escape to the cool, low-pressure surface. Hence we find the phenomena of volcanism, intrusion and mineralization which are so closely knit together in time and place within the limits of the intersections or geologic crossroads".

The structural conditions noted by Billingsley and Locke, although not identical with those found near the Big Pine volcanoes, are obviously analogous. The flat and shallow Tertiary overthrusts are represented at certain localities along the Sierra Nevada front by what appear to be steep, deeply penetrating upthrusts of probable Jurassic age. Moreover, the structures that intersect the inferred thrust arc near Big Pine appear to be faults rather than folds. Nevertheless, it is thought that the principle involved in Billingsley and Locke's generalization applies as a theory of the position of the Big Pine volcanoes. In other words, complicated deformations, including thrusting, in the area of structural intersection south of Big Pine, have opened deeply penetrating channels for the escape of melts. Further, it seems that within this area of intersection lies a miniature of the structure that localized the volcanic field. This miniature may have provided the only outlet suitable for the escape of the viscous, sluggish rhyolite which, in contrast to the fluent basalts, had to be kneaded, fluxed, and squeezed slowly upward through the cold crust.

At the risk of overemphasis, the idea of structural intersections has been discussed here at some length, because, insofar as the writer is aware, this concept has received little attention in the literature but promises to be of great scientific and practical importance. Future studies of volcanic fields, intrusions, or mining districts might

well lead to more serious attempts to explain the positions of these features in the regional structure.

REMELTING, INFLATION, AND FORM OF THE RHYOLITE

Effect of remelting.—As previously stated, one of the results of remelting the obsidian was to convert resistant, congealed masses into mixtures that were again capable of flow. By this means, the general fluidity of the rhyolite must have been increased, and the period of flow prolonged. This increased fluidity must have been an important factor in determining the cakelike form (Fig. 2), for otherwise a group of steep-sided domes, or spines, might have resulted.

The flow was severely limited by the amount of heat available and by the high viscosity characteristic of siliceous melts. The tendency to spread as a thin sheet was also opposed by the exsolution of gases at low pressure, thought to have resulted at many places directly from remelting. The loss of dissolved gases, including water, raises the viscosity of a siliceous melt. Further, exsolution of gases would inflate a viscous melt, thus increasing the volume and thickening the mass.

Gas-inflation and growth of the volcano edifice.—The proof of volume increase in the lava is furnished by the gas pores which become more abundant from obsidian through gray lava to pumice. The conversion of much obsidian to gray lava must have been accompanied by very marked volume increase, possibly 25 per cent, or more, of the original volume. The formation of some of the pumice may have caused a volume increase of several hundred per cent. If so, it is no surprise to find that the summit mounds and the higher parts in general are composed mainly of pumice and that the obsidian and denser parts of the gray lava are more common to lower parts of the structure.

During its growth, the volcano edifice apparently rose gradually. The summit mounds, thought to be situated above the principal magma outlets, were formed where the largest increments of heat would cause the most active remelting, which would result in the most extreme gas-inflation and uplift. The most rapid inflation of the lava would also cause the most rapid congealing. The explosive escape of gases from these rapidly congealing domes of pumice must have been responsible for the previously mentioned pipes of pumice breccia, found on and near the summit mounds.

Although continued upheaval of the rhyolite by gas-inflation has been emphasized, repeated eruptions of fresh magma also were important factors in the growth of this volcano. The available evidence does not allow the results of additions of fresh magma to out weigh the results of gas-inflation. Likewise, it is not possible to say how much of the gas-inflation resulted from remelting of dense obsidian and how much from the exsolution of gases from eruptions of fresh, unchilled magma.

Obviously, the present form of the rhyolite is a compromise, modified somewhat by erosion, between many opposing factors some of which favored ease of flow and spreading, whereas others tended to upheave, thicken, and chill the magma.

SUMMARY OF CONCLUSIONS

The basaltic field south of Big Pine, California, contains a single mass of rhyolite. Considerations of form and internal structure lead to the conclusion that this rhyolite

was erupted in place. The volcanic field occupies an imposing intersection in the pattern of regional structure, and the rhyolite apparently issued from a structural intersection within the larger area of intersection.

The study of the varieties of rhyolitic lava, and their structural relations to one another, revealed that much of the obsidian had been remelted and inflated to form gray lava and possibly pumice. Some gray lava may have been remelted and converted to pumice, but of this no convincing evidence was found.

The increments of heat, which caused the remelting, prolonged the period of general fluidity and tended to spread and flatten the mass. The escape of dissolved gases consequent upon remelting, and possibly upon the introduction of fresh magma to the low-pressure surface, tended, on the contrary, to inflate, uplift, and chill the mass and to prevent spreading. The present form of the rhyolite is a compromise between these opposing factors.

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LATE PALEOZOIC STRATIGRAPHY, WEST-CENTRAL AND NORTHWESTERN COLORADO

BY KENNETH G. BRILL, JR.

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ABSTRACT

The Pennsylvanian and Permian (?) sediments in west-central and northwestern Colorado crop out in an area of nearly 2300 square miles. Deposited in a trough between the Front Range landmass and Uncompahgre landmass, they consist mainly of red beds and coarse clastic sediment. Some gypsum and marine limestone occurs in the lower part of the sequence.

The Belden shale, composed of dark shale and limestone, is ranked as a formation instead of a member. It replaces the Weber shale as applied to the basal Pennsylvanian in Colorado and is Des Moines in age. The Maroon formation, which rests on the Belden, consists of several thousand feet of red beds. Much, if not all, of it is Des Moines in age. All the gypsum in the lower Maroon is of Des Moines age. The term Weber quartzite is restricted in west-central Colorado to a white

sandstone overlying the Maroon formation. The overlying widely distributed State Bridge formation is composed mainly of fine-grained, red, clastic sediment which attains a thickness of more than 5000 feet along the axis of the trough. It is believed to correlate with the Permian Phosphoria formation of northwestern Colorado.

INTRODUCTION

In west-central and northwestern Colorado the late Paleozoic strata cover nearly 2300 square miles in parts of Gunnison, Pitkin, Eagle, Routt, Garfield, Rio Blanco, and Moffat counties.

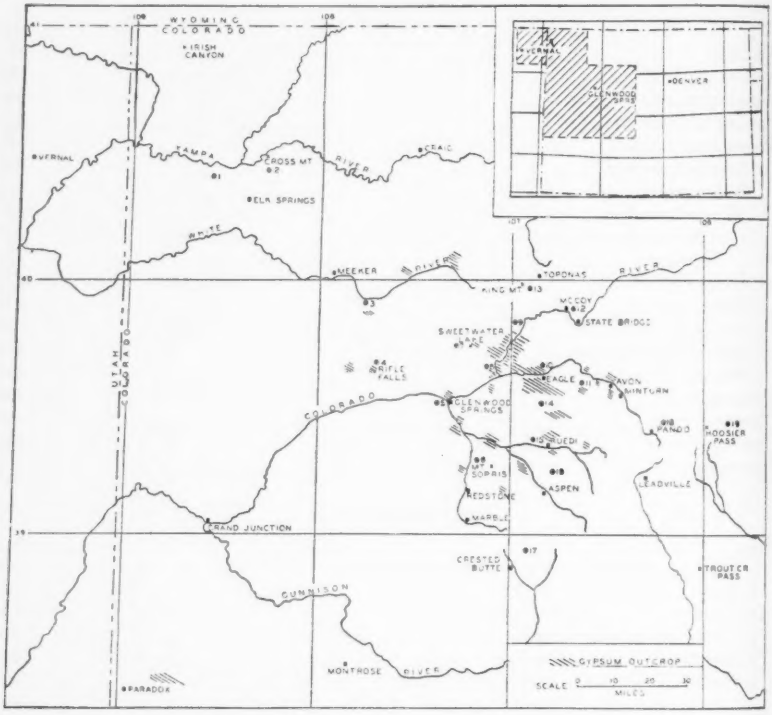

FIGURE 1.—*Index map showing location of sections by number*

The sediments consist mainly of red and gray clastics and gypsum. They are exposed in broad domes, monoclinal and anticlinal areas where erosion has stripped away the younger beds. The red beds thicken southward from a few hundred feet in southeastern Routt County to more than 13,000 feet in Pitkin County. Diagnostic fossils in these strata are rare. Lateral variation may be so great that detailed sections a few miles apart show no beds that appear to be common to both. Thus a multiplicity of stratigraphic names has appeared in the literature. New terms have been introduced, and old names carried from one district to another have been misapplied.

The present work was undertaken (1) to make correlations throughout the region, (2) to clear up confusion in the stratigraphic nomenclature, (3) to date the detrital sediment, (4) to determine the source of the sediment and relation of highlands to seaways.

The field work was done during the summers of 1941 and 1942. The writer previously had spent two summers in the Gore and neighboring areas. Over 30 detailed stratigraphic sections were measured with a Brunton compass used as a hand level.

The geologic map of Colorado (1935), scale 1/500,000, shows the main structural features and many of the stratigraphic units recognized in the region. The U. S. Geological Survey topographic sheets which cover it in part are: Leadville, Mt. Jackson, Aspen, scale 1/125,000; Minturn, Crested Butte, Glenwood Springs, scale 1/62,500; Tenmile Special, scale 1/31,680, and Snowmass Mountain, scale 1/48,000. Planometric maps of the U. S. Forest Service which cover the wooded areas are: Arapahoe National Forest, Holy Cross National Forest, White River National Forest and Gunnison National Forest.

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PREVIOUS NOMENCLATURE

The earliest important literature of the region was in the reports of Marvine (1874) and Peale (1876). At that time the lower red beds were considered Pennsylvanian, and above them the Permian was recognized. King (1876) gave the name Weber to late Paleozoic quartzites in the Uinta Mountains, Utah. Emmons (1882) used the terms Weber shale and Weber grit for two Pennaylvanian units in the Leadville district. Emmons *et al.* (1894) employed the term Weber formation in the Crested Butte district. Although Girty (1903) stated that the term Weber was confusing and that it should be abandoned in west-central Colorado, it continued to be used.

Emmons *et al.* (1894) also proposed the term Maroon conglomerate for the red beds between the Weber formation and the Jurassic. Emmons (1898) applied the name Maroon formation to a series of red beds in the Tenmile district. The red beds above the Maroon in this district were assigned to the Wyoming formation, but this term was later abandoned and the Maroon formation extended upward to include all the red beds (Johnson, 1934). Emmons proposed two other formation names in the same paper, the Robinson limestone between the Weber and Maroon

formations and the Jacque Mountain limestone between the Maroon and Wyoming formations. Spurr (1898) extended the range of the Maroon laterally from the type section into the Aspen district.

Crawford (1913) named two formations in the Monarch and Tomichi district—the Garfield formation and the Kangaroo formation above. The latter he correlated with the Maroon.

The name Hermosa formation was proposed by Cross and Spencer (1899) for gray sandstone, shale, and limestone of Pennsylvanian age in the San Juan district of southwestern Colorado. This term has been used by Vanderwilt (1935; 1937) in the Elk Mountains of west-central Colorado for beds equivalent in age to the Hermosa but on the opposite side of the Uncompahgre Highland and in a different basin of sedimentation.

Roth (1930) proposed the term McCoy formation for about 1100 feet of red beds in the McCoy area, Eagle County. Donner (1936) extended the thickness of the McCoy formation and suggested two members for the overlying Maroon formation, the "Rock Creek conglomerate" below and the State Bridge siltstone above. Bassett (1939) used Donner's terms "Rock Creek" and State Bridge as members of the Maroon formation in the vicinity of Dotsero. However, the term Rock Creek is preoccupied.

The writer (1942) proposed the term Battle Mountain formation for Pennsylvanian strata in the Gore area. The Belden shale was proposed as a basal member, and Emmons' Robinson limestone and Jacque Mountain limestone were also made members of the Battle Mountain.

In northwestern Colorado the term Weber quartzite has been applied correctly to a thick, white sandstone of Pennsylvanian age. Between the Weber and the Mississippian a group of sandstone, shale, and limestone has been called Older Pennsylvanian in the literature (Sears, 1925). Above the Weber a thin sequence of shale and sandstone has been referred to the Park City by Sears (1925).

REVISED NOMENCLATURE

GENERAL STATEMENT

An attempt has been made to restrict the use of, and to correct the misuse of, previous stratigraphic names rather than to add new names to the literature.

BELDEN SHALE

The Belden shale member of the Battle Mountain formation was proposed by the writer (1942) for the basal limestone and dark shale sequence of Pennsylvanian age. Its type section is about 4 miles south of Minturn, Colorado (Pl. 2, fig. 3).

The Belden member extends over much of the Pennsylvanian basin of west-central Colorado and is the same age at all localities studied. Therefore the Belden shale member is raised to formational rank. The new formation is equivalent to the "Weber shale" throughout this region.

The base of the Belden shale is clearly defined by an erosional contact with the pre-Pennsylvanian. A karst topography developed on the surface of the Mississip-

FIGURE 1. MAROON FORMATION
Conglomerate with red sandstone matrix on Cement Creek 7.5 miles northeast of State Highway 135. Limestone boulder to left of hammer contains Des Moines fossils.

FIGURE 2. MAROON FORMATION AND WEBER QUARTZITE
On South Canyon Creek 4 miles west of Glenwood Springs. At right are conglomerate beds of Maroon formation. Weber quartzite forms knob in center.

FIGURE 3. MAROON FORMATION
Gypsum dome on the north side of Eagle River 5 miles west of Eagle. (Photo by G. M. Ehlers)

FIGURE 1. STATE BRIDGE FORMATION
Fine-grained, cross-bedded sandstone of interval 37, Frying Pan Creek section, 6 miles west of Reudi.

FIGURE 2. STATE BRIDGE FORMATION
Type section .5 mile north of State Bridge. Prominent ledge in foreground contains pelecypod fauna.

FIGURE 3. BELDEN SHALE
Black shale and thin limestone 4 miles south of Minturn near type section.

pian limestone and dolomite before the region was buried by the sediments of the encroaching Pennsylvanian sea. Numerous filled caves, natural bridges, pinnacles, and other solution features appear where this former surface has been exhumed. A

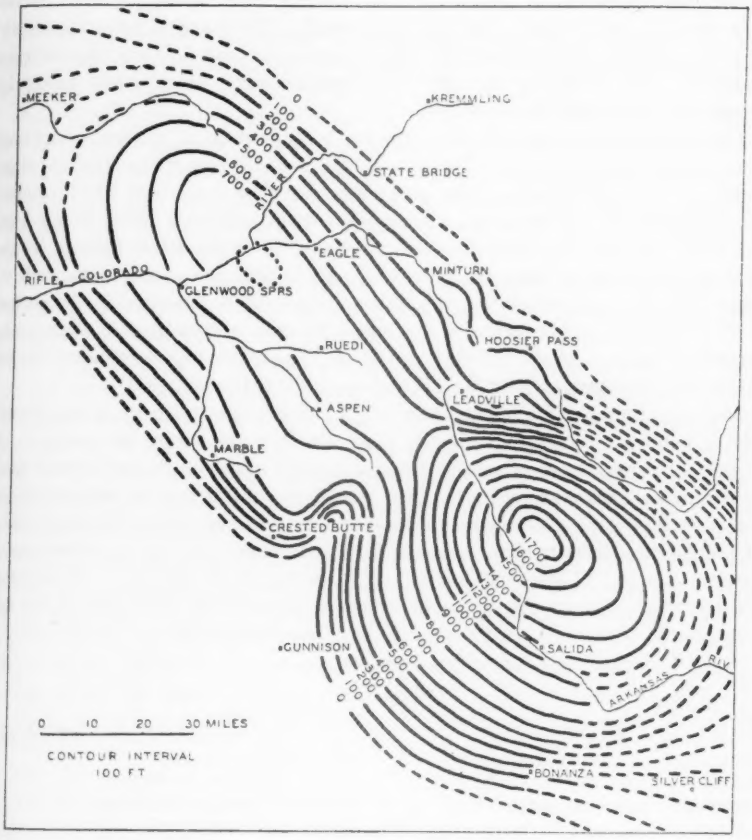

FIGURE 2.—*Isopach map of the Belden shale*

regolith of red or yellow shale with occasional limestone boulders commonly rests upon the contact. Overlying the regolith gray and black shales and argillaceous limestone are interbedded. Locally thin beds of impure coal (Hills, 1886) and sooty layers are intercalated. The Belden shale reaches a maximum thickness of over 1700 feet at Trout Creek Pass (Gould, 1935). At Pando and east of Crested Butte it is about 100 feet thick. It is absent in the McCoy area and in Moffat County. Figure 2 indicates that this formation is thin or absent along the margins of the trough.

Numerous fossiliferous black shales interbedded with coarse-grained red beds in the lower part of the McCoy formation suggest that the Belden may grade into a

near-shore facies toward the highlands. Variations in fossil assemblages between the center of the basin and the margins may be explained by ecological differences.

Dark shale deposition may have been confined to the central part of the trough. The red-bed deposition on the margins may coincide with the deposition of the red beds overlying the Belden in the axis of the trough. The marginal areas apparently were not covered with black shale, because caves and sink-holes in Mississippian limestone north of McCoy are filled with red sandstone which would hardly be present had shale been deposited first.

The dark sediment, derived from the low-lying surface of the newly upraised Ancestral Rockies, was deposited in a trough 80 miles wide between the Uncompahgre and Front Range Highlands. The trough was very close to sea level which resulted in interbedded marine limestone, carbonaceous shale, and coal. Most of the limestone beds are thin, but along the western edge of the White River Plateau several beds exceed 30 feet in thickness. The number and thickness of nonclastic beds increase westward, suggesting that this unit may be entirely limestone in the portion of the trough buried beneath the younger sediments in western Rio Blanco and Garfield counties. At the southern end of the trough this unit correlates with the Magdalena limestone of New Mexico (Johnson, 1929; Heaton, 1933).

The isopach map of the Belden shale (Fig. 2) illustrates a relatively narrow trough with a greater thickness of sediment along the axis than near the margins. It further indicates a basin of maximum accumulation to the south and a lesser basin to the north. These are separated by a constriction of the seaway between Pando and Crested Butte. These structural basins seem to be related to the localization of the gypsum deposits of the region. Stratigraphically, the lowest occurrence of gypsum is a bed 13 feet thick near Dotsero, not far from the center of the more northerly basin. Although the accuracy of the isopach map is limited by the fact that the top of the unit is set arbitrarily, it is reasonably correct.

Fossils collected from the Belden shale are:

colonial corals
crinoid columnals and plates
Archeocideris sp. (plates and spines)
bryozoans
Orthotichia schuchertensis Girty
Chonetina flemingi cf. *plebia* Dunbar and Condra
Paeckelmannia n. sp.
Mesolobus mesolobus (Norwood and Pratten)
Juresania nebraskensis (Owen)
Dictyoclostus portlockianus (Norwood and Pratten)
D. inflatus coloradoensis (Girty)
Linoproductus sp.
Marginifera muricatina Dunbar and Condra
M. missouriensis (Girty)
Cancrinella boonensis (Swallow)
Squamularia perplexa (McChesney)
Spirifer rockymontanus Marcou
Neospirifer sp.
Composita subtilita (Hall)
C. cf. *C. ovata* Mather
Astartella concentrica (Conrad)
Schizodus sp.
Pseudorthoceras sp.

This assemblage indicates correlation with the Cherokee of the Mid-Continent region.

The Belden shale is correlated with the lower part of the Garfield formation in the Monarch district, the Weber shale of the Leadville district, the Weber formation of the Salt Creek area, the Molas formation of the San Juan district, the Glen Eyrie

shale of the eastern Front Range, and perhaps the lower portion of the McCoy formation. It may correlate with the upper Amsden formation of Wyoming.

MAROON FORMATION

General considerations.—The name Maroon was proposed by Emmons *et al.* (1894) in the Crested Butte district. It is here applied to a thick sequence of Pennsylvanian sediments overlying the Belden shale.

In this region authors have given Maroon equivalents a variety of names: Weber grit, Coffman conglomerate, "Rock Creek conglomerate," McCoy formation, Battle Mountain formation, Kangaroo formation, and Hermosa formation. The dearth of suitable marker beds, rapid lateral variation in color, thickness, and lithology, and lack of unbroken sequences have caused each worker to adopt his own nomenclature.

This formation consists of red, yellow, and brown shale, sandstone, arkose, and conglomerate with intercalated beds of gypsum and thin limestone. It is found throughout the Paleozoic trough in west-central Colorado.

The contact with the Belden shale is gradational. Its lower limit is drawn arbitrarily where the coarse clastics predominate over dark shale and limestone.

Faulting and warping have so disturbed this region that an unbroken detailed section from the Mississippian to the Triassic is almost impossible to find. In the southern part of the trough Triassic erosion has removed the top of the section. Figures 3 and 4 illustrate that in spite of erosion the sediments thicken toward the south. In the McCoy area beds equivalent to the Maroon are less than 3500 feet thick. Eighteen miles south on Eagle River, near Diamond J ranch, a section without an exposed base is about 3000 feet thick. (The log of a well drilled in SW$\frac{1}{4}$ sec. 34, T. 4 S., R., 85 W., indicates at least 800 feet more of this section.) Twelve miles farther south on Hardscrabble Mountain detailed section no. 14 is 5000 feet thick with no base exposed. On Woody Creek 22 miles farther south, in detailed section no. 16, the Maroon is about 7000 feet thick. Twenty-three miles south in the Crested Butte district detailed section no. 17 measures 5000 feet with the top removed by erosion.

The lower portion of this unit is gray, yellow, or brown. The upper portion is invariably some shade of red. The color change between the upper and lower parts is gradual. The grain size of the Maroon is quite variable. In numerous localities cyclothems are apparent (Brill, 1942). Conglomerates are composed of rounded or subangular pebbles of acid igneous and metamorphic rocks with occasional pebbles of limestone. On Cement Creek 8 miles east of Crested Butte many pebbles and boulders in the Maroon are limestone (Pl. 1, fig. 1). These contain fossils of Des Moines age, which suggests that the limestone was broken up shortly after cementation and was then incorporated into the Maroon with a red sand matrix. Similar, but fewer, boulders occur in the McCoy area. Conglomerate, sandstone, and siltstone commonly contain unaltered potash feldspar.

Limestones occur throughout the formation, being especially numerous in the lower part. With the exception of several thick beds of limestone and dolomite on the eastern and northeastern side of the region, the limestones rarely exceed 2 feet

in thickness. All are lenticular; however, some of the thicker beds, such as the Jacque Mountain and Robinson limestones of the Gore area, may be traced for a score of miles.

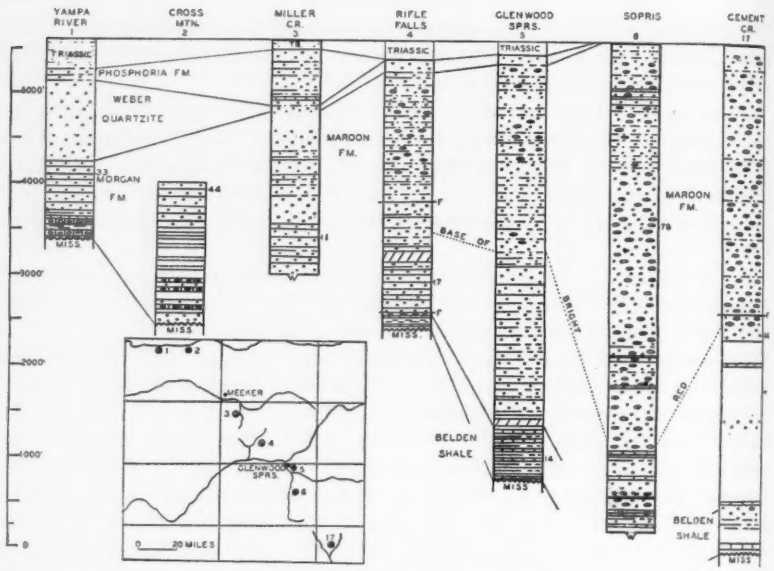

FIGURE 3.—*Correlation of columnar sections*

Datum Shinarump conglomerate or equivalent position. Interval number refers to highest bed with diagnostic fossils.

During Maroon time course clastics were deposited in deltas along the margins of the trough. The fine-grained sediment was carried into the center. Although separation of the intertonguing and superposed deltas may be made along the borders, correlation of deltas with the fine-grained equivalents in the center is difficult. The bedrock of the flanking highlands seems to have been similar mineralogically, thus samples from both sides of the trough have identical mineral assemblages (P. D. Krynine, written communication, 1939). In the absence of clearly defined mineral provenances, color, lithology, and gradations in texture can be used to a limited extent in transbasin correlation.

Deltas, which had their origin in the Front Range highland, are reported by Singewald, Donner, and Bassett. Singewald (1942) reported several in the lower Maroon of the Beaver-Tarryall district, one of which he correlates with the Coffman conglomerate of the Salt Creek area (Gould, 1935). Donner (1936) in the McCoy area recognized a delta just beneath the State Bridge formation which he called in manuscript the "Rock Creek" conglomerate. Bassett (1939) in the Dotsero area uses the term "Rock Creek" conglomerate for a local delta. He suggests, "that the

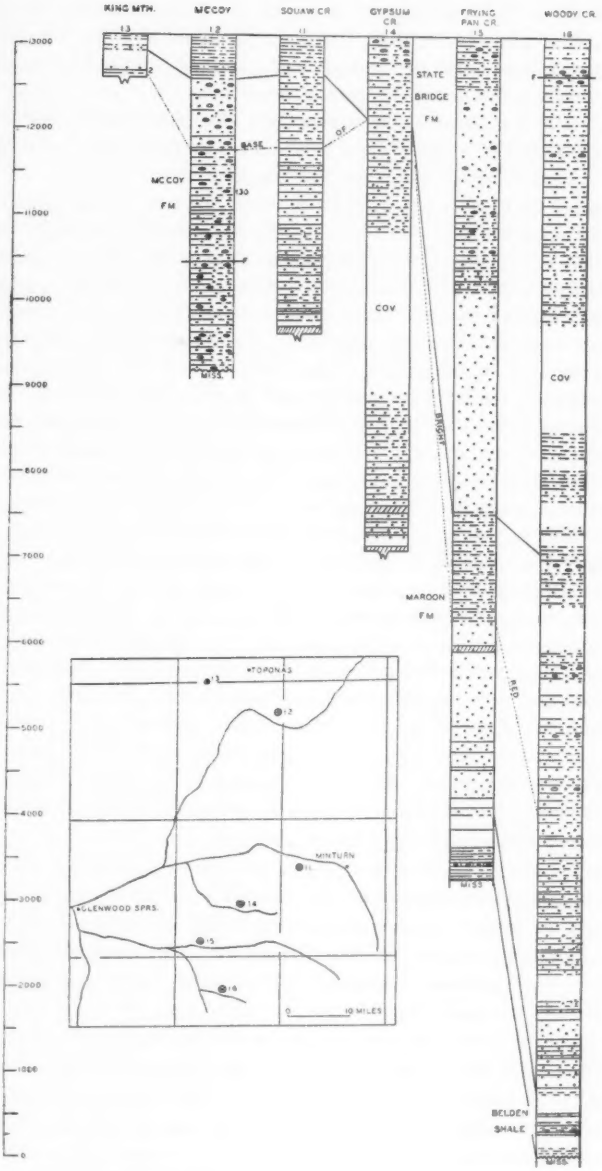

FIGURE 4.—*Correlation of columnar sections*

Tatum Shinarump conglomerate or equivalent position. Interval number refers to highest bed with diagnostic fossils.

gray sandstone section near Dotsero overlying the McCoy (Belden of this paper), may be the equivalent of the Rock Creek conglomerate and that the gypsum and red beds may correspond to the State Bridge siltstone" (of the McCoy area). Although Bassett's surmise may be correct concerning the "Rock Creek," it seems more likely, after a study of numerous sections, that the "Rock Creek" equivalent in the Dotsero section is fine-grained sandstone and shale about 1000 feet stratigraphically above the gray sandstone and conglomerate.

In the upper Maroon of the Rifle Falls and Glenwood Springs areas thick conglomerate beds represent a delta which originated in the Uncompahgre highland to the southwest. Similar conglomerates, but at a lower stratigraphic horizon, in the vicinity of Mount Sopris, Redstone, and Crested Butte (Pl. 1, fig. 1) suggest other deltas with the same source. Maroon sediments in the Gypsum Creek (no. 14), Frying Pan Creek (no. 15), and Woody Creek (no. 16) detailed sections undoubtedly represent tongues from both sides of the trough. The thin conglomerates of the Woody Creek section are the basinward edges of deltas from the west.

Colonies of the coral *Chaetetes milliporaceus*, regarded as a guide fossil to the earlier Pennsylvanian, occur about 1200 feet beneath the top of the Sopris detailed section (no. 6). The colonies occur in a conglomerate and may be merely boulders reworked by erosion; however their upright position on the outcrop and the fact that they are larger and less rounded than the igneous rock pebbles suggest strongly that they grew *in situ*. The presence of small reefs of *Chaetetes* associated with coarse clastics at other localities within the region indicates that this is not unusual. If these forms grew in place nearly all the Maroon is definitely Des Moines in age.

In the Maroon equivalent of the Gore area the highest horizon with diagnostic marine fossils is interval 206 of the Battle Mountain formation. It is 4788 feet above the Mississippian. An ostracod fauna indicates that the bed is of Marmaton age (Brill, 1942). In Figure 6 in the Pando detailed section (no. 18) interval 117 is equivalent to interval 206 of the type section of the Battle Mountain formation. The stratigraphic position of this bed may be compared with that of the *Chaetetes* bed, interval 78 of Sopris detailed section (no. 6). These beds are apparently in very nearly the same stratigraphic position.

The Jacque Mountain limestone (Fig. 6, section 18) named by Emmons (1898) in the Tenmile district is a fossiliferous bed. It is over 5000 feet above the Mississippian at its type section. Although Emmons assigned it to the Coal Measures its fauna is long-ranged and may be either Pennsylvanian or Permian. This formation may be present in the Beaver-Tarryall area (Singewald, 1942) but is not recognizable north or west of the Gore area.

In the lower part of the Maroon it is possible to find the remains of such plants as *Walchia* sp. (Gould, 1935; Donner, 1936; Arnold, 1940), *Neuropteris* sp., and *Odontopteris* sp. (C. A. Arnold, oral communication). *Walchia* is present in several localities in the region, along the Eagle River, on Gypsum and Frying Pan creeks, as well as in the Gore and McCoy areas.

The fauna of the Battle Mountain formation has been mentioned in a previous

paper (Brill, 1942). The fauna of the Maroon formation is of course similar. Fossils found on the west side of the trough are:

Chaetetes milliporaceus Milne-Edwards and Haime
Orbiculoidea missouriensis (Shumard)
Chonetes sp.
Dictyoclostus portlockianus (Norwood and Pratten)
D. americanus hermosanus (Girty)
Marginifera muricatina Dunbar and Condra
M. ingrata Girty
Hustedia cf. *H. mormoni* (Marcou)
Composita subtilita (Hall)
C. sp.

The lower Maroon is correlated with the Cherokee and Marmaton of the Mid-Continent region. To the upper unfossiliferous part no age except Pennsylvanian may be assigned. There are no unusual stratigraphic breaks in this sequence or between it and the underlying Des Moines portion, and it underlies a probable equivalent of the Weber quartzite. The entire Maroon may be Des Moines in age.

The Maroon bears a fauna similar to that of the Hermosa formation of the San Juan district and also appears to be the same age as the lower Tensleep sandstone of Wyoming (Branson, 1939). In lithologic characteristics and stratigraphic position it resembles the Fountain formation of the eastern Front Range. It is approximately the same age as the Morgan formation of Utah.

Gypsum.—Abundant gypsum (Fig. 1) is found only in the northern basin of the trough (Fig. 2). Toward the eastern side of the trough gypsum deposits wedge out into sediments with marine fossils, indicating that in the Gore and McCoy areas normal marine conditions prevailed while in the center more rigorous conditions limited life to algae and scavengers. Above the gypsum in the center only algal limestones, ganoid fish scales, and a prawn, *Arthropalaemon* sp., were found.

Masses of gypsum do not seem to follow any particular stratigraphic horizon, although they occur in the lower gray and yellow portion of the Maroon rather than the upper red. A thin persistent bed occurs in the Belden shale in the Deep Creek detailed section (no. 8).

Some undisturbed gypsum beds have been found; however, most outcrops show the affects of tectonic movement associated with the Laramide Revolution (Pl. 1, fig. 3). They occur as domes or irregular anticlines and may be 600 feet thick. The greatest thickness is in the Deep Creek detailed section (no. 8) where gypsum aggregates nearly 1000 feet in six beds (Fig. 5). Many deposits are capped by unfossiliferous, cavernous limestone up to 15 feet thick. Large deposits are found north and south of the Eagle River between Avon and Dotsero (Burchard, 1910).

The post-Belden gypsum deposits may have been localized by the structural trends of Belden time. A constriction of the trough between Leadville and Crested Butte (Fig. 2) separates the larger, southern structural basin from the smaller, northern basin. In Maroon time this narrows may have acted as a lip over which the water flowed from the southern toward the northern basin. The filling of the northern basin with normal marine water kept pace with evaporation and allowed the accumulation of evaporite. Lenticular beds of gypsum were thus deposited in shallow lagoons or bays separated by bars. Although saline deposits have been

reported in Paradox Valley (Baker *et al.*, 1933) west of the Uncompahgre highland, none have been found in this part of the State.

At Avon near the eastern limit of the gypsum deposit numerous specimens of *Marginifera muricatina* were found in limestone between two layers of gypsum. Des

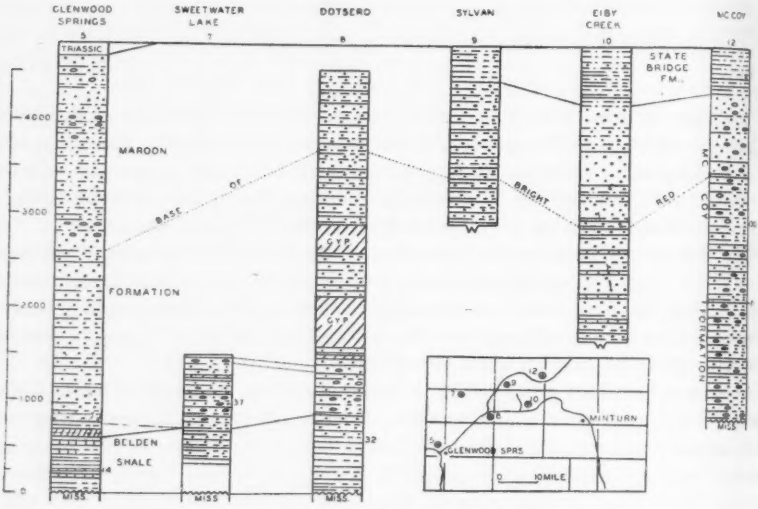

FIGURE 5.—*Correlation of columnar sections*

Datum Shinarump conglomerate or equivalent position. Interval number refers to highest bed with diagnostic fossils.

Moines fossils have been found on the flanks of the trough well above the evaporite. All the gypsum is Des Moines, and probably Cherokee in age.

MORGAN FORMATION

The term Morgan was proposed by Blackwelder (1910) for terrestrial beds beneath the Weber quartzite in Weber Canyon, Uinta Mountains, Utah.

In Moffat County, Colorado, several hundred feet of Pennsylvanian sediment, between the Mississippian and the Weber, has been called "Older Pennsylvanian" (Schultz, 1920; Sears, 1925). The name Morgan is here applied to these sediments because in appearance and origin they resemble the Morgan of Utah rather than the Maroon of Colorado.

The lower contact is usually obscured by the basal shales of the Morgan, but where the contact was observed it is conformable with the Mississippian limestone. The Morgan formation of Moffat County consists of red and white, fine-grained sandstone with intercalated shale and crystalline marine limestone.

According to Williams (1943) the Morgan thickens east and west from the Duchesne River region in the Uinta Mountains, where it is 210 feet thick. To the east on Brush Creek, north of Vernal, Utah, it is 382 feet thick. Near Irish Canyon, Colorado (Fig. 1), it is 525 feet thick (Sears, 1925). Near Elk Springs, Colorado, it is 941 feet

thick, and on Cross Mountain (Fig. 3) northeast of Elk Springs it is more than 1500 feet thick with no top exposed.

The following fossils were collected from limestone beds along a tributary of Disappointment Creek sec. 2 T. 5 N., R. 100 W.:

Fusulinella sp.
Archeocidaris sp.
Fenestellid bryozoans
Orbiculoidea sp.
Orthotichia schuchertensis Girty
Echinoconchus cf. *E. semipunctatus* (Shepard)
Dictyoclostus portlockianus (Norwood and Pratten)
Linoproductus prattenianus (Norwood and Pratten)
Spirifer rockymontanus Marcou
Neospirifer cf. *N. cameratus* (Morton)
Composita ovata Mather
C. cf. *C. subtilita* (Hall)
Aviculopecten sp.

This fauna indicates that the Morgan formation here, as elsewhere, is of Des Moines age.

Probably the Morgan has more than one source of sediment. The sandstone of the eastern Uinta Mountains is similar to that in Moffat County and was apparently derived from a western extension of the Front Range highland. Although the writer has not measured detailed sections in the western end of the Uinta range, the conglomerate and coarse clastics in the Morgan of that region (Williams, 1943) suggest a local source farther west.

The Morgan formation is equivalent to the Maroon formation. The lower part of the Morgan may correlate with the Belden shale and upper Amsden formation.

WEBER QUARTZITE

This name was proposed by King (1876) for exposures of light-colored quartzite in Weber Canyon, Uinta Mountains, Utah. This term was formerly applied to the Belden shale and basal Maroon in west-central Colorado. In this paper the term is applied to lithologic equivalents of the Weber of the Uinta Mountains.

This formation lies conformably on the Morgan and Maroon formations. The contact with the Morgan is gradational but more abrupt with the Maroon. The Weber consists of yellow, white, and buff, fine- to medium-grained sandstone.

The formation thins gradually from Moffat County toward west-central Colorado (Fig. 3). Near Irish Canyon Sears (1925) measured 900 feet of white quartz sandstone. On Disappointment Creek (Yampa detailed section, no. 1) the Weber is 880 feet thick. On the East Fork of Flag Creek, 6 miles south of Meeker, 60 feet of petroliferous, gray sandstone occurs near the top of the red beds. Microscopic examination indicates that the upper half of this unit resembles the Weber of Moffat County more than does the lower. The former is composed of oil-stained, subangular, clear quartz. It is less angular and finer-grained than the typical Weber and contains mica and tourmaline which are absent in the Weber of Moffat County. The lower half consists of yellow and white sandstone which seems to be present in interval 56 of the Miller Creek detailed section 11 miles to the east. It is present 16 miles still farther east between Marvine and Lost Creek Ranger Station where the upper half is absent.

The Weberlike tongue reappears on the East Fork of Rifle Creek 17 miles southeast

of the Flag Creek locality. Here it is represented by 100 feet of petroliferous, gray sandstone at the top of the Paleozoic red beds (Rifle Falls detailed section, no. 4). Microscopic examination reveals fine-grained, subangular, clear quartz, which contains fragments of orange rutile similar to the typical Weber. Fragments of mica and chlorite are present. On South Canyon Creek, 22 miles southeast of the Rifle Falls locality, 100 feet of petroliferous, gray sandstone (Pl. 1, fig. 2) appears again at the top of the Paleozoic section (interval 68, Glenwood Springs detailed section, no. 5). This is unquestionably the same bed that occurs on Rifle Creek.

The Weber cannot be traced eastward into the Eagle basin with any degree of certainty. North of Eagle in the Sylvan detailed section (no. 9) and Eiby Creek section (no. 10, interval 77) a fine-grained, white sandstone occurs well up in the red beds. In both localities the thickness is 46 feet. Those two sections lie about 25 miles northeast of the South Canyon locality and are on the east side of a dome from which the red beds have been stripped. Correlation with the Weber is made on the basis of stratigraphic similarity and faint mineralogical similarity. Although the white sandstone is contaminated with floods of minerals from another provenance, it is fundamentally a fine-grained, subangular, clear quartz sand.

It is believed that this sandstone in the Glenwood Springs and Rifle Falls detailed sections is equivalent to the Weber because (1) this interval is above the Maroon formation, (2) it contains clear quartz and orange rutile, (3) it is the only late Paleozoic petroliferous sandstone in west-central Colorado, and the Weber-Tensleep is an oil horizon. On the other hand lack of fossil evidence and inability to make direct correlation weaken the argument. Subsurface work in northern Rio Blanco County between Meeker and Elk Springs will undoubtedly make stratigraphic relations clear.

No fossils have been reported from the Weber of Colorado. In the Uinta Mountains fossils in the lower beds of this formation have led Williams (1943) to state "... most if not all of the Weber is of Des Moines age." If, as most workers agree, it is correlative with the Tensleep sandstone of Wyoming, it is Pennsylvanian. Complete faunal studies of the Tensleep have not been made; however, workers in southern Montana and Wyoming consider it to belong to the Des Moines (Love, 1939; Branson, 1939). Miller and Thomas (1936) report Upper as well as Lower Pennsylvanian faunas from the Casper formation of southeastern Wyoming. They believe that the Casper is "about the same age as the Tensleep." This suggests that the upper part of the Tensleep is late Pennsylvanian whereas the lower part is Des Moines.

The Weber of west-central Colorado may be a tongue representing late Pennsylvanian sedimentation, which extends southward into the red beds from the upper Tensleep of Wyoming. In this there is a parallel in the Upper Pennsylvanian Casper formation which interfingers with the upper Fountain formation in southeastern Wyoming (Miller and Thomas, 1936). Heaton (1933) suggests that the Weber of northern Utah is older than all the Tensleep, which would make it older than the Weber of the Uinta Mountains. The Tensleep-Weber unit seems to be older near its source than farther south. Branson (1939) also states that the Tensleep is a retreatal sandstone.

If all the Weber is Des Moines, as Williams suggests, the Weber of west-central

Colorado may represent a tongue of the Tensleep which is younger than Cherokee and probably late Marmaton in age.

PHOSPHORIA FORMATION

The term Phosphoria was proposed by Richards and Mansfield (1912) for Permian exposures in southeastern Idaho. This formation may be traced from the type locality across northwestern Utah (Williams, 1939) into Moffat County, Colorado, where it is composed of gray shale, chert, and thin limestone beds conformable on the Weber quartzite.

Near Irish Canyon Sears (1925) measured 115 feet of Park City. On Disappointment Creek (Yampa detailed section, no. 1) the writer measured 114 feet of gray shale which is equivalent to the beds near Irish Canyon. Between the gray beds and the Shinarump conglomerate is 218 feet of red shale and siltstone. A part or all of these red beds may represent the eastern extension of the Mackentire red bed tongue of the Phosphoria. Williams (1939) was unable to establish with certainty the Permian-Triassic contact in the Uinta Mountains, and no stratigraphic break between these systems appears in Moffat County.

Scattered fossils in the vicinity of Irish Canyon indicate that this sequence correlates with the Phosphoria of Wyoming and Utah. Its correlation with the State Bridge is discussed later.

STATE BRIDGE FORMATION

The name State Bridge siltstone was applied by Donner (1936) to the upper member of the Maroon red beds in the McCoy area. Bassett (1939) mentioned the term in connection with the red beds near Dotsero, Colorado. Because of the persistence of the unit the writer (1942) raised the State Bridge to the rank of formation.

In the type section at State Bridge, Colorado (Pl. 2, fig. 2), it consists of brick-red and yellow siltstone and shale. South of the type locality it is largely red siltstone, but tan, fine- and medium-grained sandstone beds are intercalated, and, near the top of the section, a few thin beds of conglomerate appear. Abundant ripple marks and thin, arenaceous, algal limestone indicate shallow-water deposition

The State Bridge thickens markedly in the southern part of the region. At the type section it is 500 feet thick. In the valleys of the Colorado and Eagle rivers it maintains a thickness of 400 to 700 feet. On Hardscrabble Mountain, north of Gypsum Creek (Gypsum Creek detailed section, no. 14), it is over 900 feet thick. Fourteen miles to the south on Frying Pan Creek it is more than 5500 feet thick (Pl. 2, fig. 1). On Woody Creek, 8 miles farther south (detailed section no. 16), the State Bridge is represented by more than 6000 feet of sediment. In the Aspen and Crested Butte districts, if the formation were ever present, erosion has removed it. In the Glenwood Springs and Rifle Falls detailed sections the State Bridge is absent, but it is represented on the East Fork of Flag Creek (6 miles south of Meeker) by about 300 feet of brick-red and yellow siltstone and shale. In this locality it rests on the Weber quartzite. At King Mountain (detailed section no. 13) about 200 feet of red siltstone rests on the Maroon formation.

The basal contact in the type section is drawn where the siltstone and shale give

way to the underlying coarse clastics. Its contact with the Weber quartzite is conformable, but it is gradational with the Maroon formation. In the Eiby Creek and Sylvan detailed sections the base is drawn at the top of the supposed Weber equivalent. There is a slight but noticeable change from coarser- to finer-grained sediment at this horizon also. Southward in the middle of the trough all sediments are relatively fine-grained; thus grain size cannot be used to separate the State Bridge from the Maroon formation. In the Gypsum Creek, Frying Pan Creek, and Woody Creek detailed sections the selection of the base is entirely arbitrary and is guided solely by the presence of marker beds within the State Bridge formation.

Several prominent horizons are useful in tracing this formation toward the south. A yellow sandstone bed lying a few feet above the supposed Weber equivalent in the Eiby Creek detailed section (interval 79) may be traced to the Squaw Creek detailed section (interval 72) where it is presumed to be close to the base of the formation. In the latter section 24 feet of tan siltstone forms the top of the formation. This siltstone lies 320 feet above the yellow bed. The tan layer is distinctive in color and may be found at the forks of Brush Creek 4 miles southeast of Eagle. On Hardscrabble Mountain it is composed of sandstone (Gypsum Creek detailed section) nearly 500 feet thick. In the Frying Pan Creek detailed section interval 35 and perhaps interval 36 represent it. Interval 35 is 1277 feet thick. In Woody Creek detailed section this bed has lost its identity but may be represented by several yellow and tan, thin sandstone layers. In this southern part of the area the base of the State Bridge is drawn arbitrarily several hundred feet beneath the tan sandstone to conform with the thickness on Squaw Creek.

The geologic map of Colorado (1935) shows the hills near Dotsero (center of T. 4 S., R. 86 W.) capped by Triassic. The writer believes that erosion has removed both the Triassic and the upper part of the Paleozoic section at this locality. The fact that the Triassic was shown on the map led Bassett (1939) to postulate the presence of the State Bridge unit at this point, but the writer did not find it.

Internal and external molds of *Myalina* sp., *Pleurophorus* sp., and *Aviculopecten* sp. are found in the type section (McCoy detailed section, no. 12) 141 feet above the base of the formation. This fauna is present 168 feet above the base of the State Bridge in the Squaw Creek detailed section (no. 11). With the exception of thin algal limestone beds and possibly some gastropods in the Beaver-Tarryall area, these are the only fossils known in the State Bridge. Norman D. Newell, who examined the pelecypods, stated (Brill, 1942) that they might be middle or late Pennsylvanian or Permian.

Stratigraphic position and such lateral tracing as is possible from the White River Plateau to Moffat County indicate that the State Bridge formation is equivalent to the Phosphoria formation. Although no diagnostic fossils have been found in the State Bridge, its fauna could be Permian.

This formation was eroded off in the southern end of the Gore area. Farther east in the Beaver-Tarryall area Singewald (1942) reports "Red shale of unknown age" overlying the coarse clastics of the Maroon formation. The writer collected small, low-spired gastropods in this shale. J. Brookes Knight states (written communication, 1943) that the form has a long range and is therefore of no stratigraphic

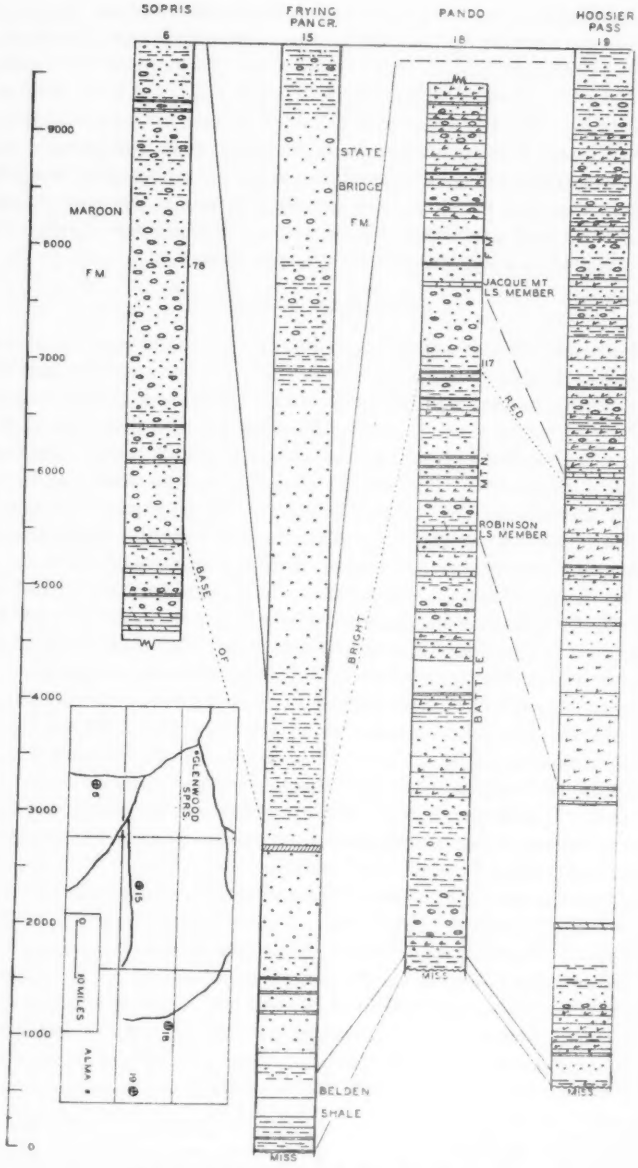

FIGURE 6.—*Correlation of columnar sections*

Datum Shinarump conglomerate or equivalent position. Interval number refers to highest bed with diagnostic fossils.

value. The lithologic character and position of the shale suggest that it may be equivalent to the State Bridge; however, such a correlation is quite tentative.

In the Salt Creek area (Gould, 1935) there are two siltstone members in the upper Maroon. The Chubb siltstone beneath is 1827 feet thick, the Pony Springs above is 6000 feet thick. The Pony Springs or perhaps both members may be equivalent to the State Bridge. This correlation is again based upon stratigraphic position, lithologic characteristics, and the general southward thickening of the formation.

A number of isolated deposits of fine-grained red beds of Paleozoic (?) age have been reported in northern Colorado (Grout *et al.*, 1913; Beekly, 1915). Possibly some of these may correlate with the State Bridge formation.

PALEOZOIC-MESOZOIC CONTACT

In west-central Colorado angular unconformites occur frequently in the red-bed section but are seemingly of minor importance. The conformable Paleozoic-Mesozoic contact is difficult to establish in many localities. The lower Triassic sediments of Colorado and Wyoming were apparently deposited in a sea transgressing from the south. The Dinwoody formation, Shinarump conglomerate, and Chinle formation (Lovering and Johnson, 1933, p. 369) on the borders of the Ancestral Rockies resemble the Paleozoic red beds because they were derived from the same source in much the same type of environment and are, in part, reworked Paleozoic sediment.

In this region the Shinarump conglomerate is the first post-Paleozoic horizon marker of any appreciable areal distribution. This excellent marker bed rests on the State Bridge formation in nearly all detailed sections north of a line between Rifle and Avon. Where the Shinarump is absent and the red shale and siltstone of the Chinle rest on similar beds in the State Bridge the contact is obscure. In the Rifle Falls and Glenwood Springs detailed sections red beds belonging to the Dinwoody (or Moenkopi) lie between the Weber and Shinarump. They are composed of shale and mudstone and do not have a lithologic equivalent anywhere in the region. On South Canyon Creek (interval 70, Glenwood Springs detailed section) *Anodontophora* sp. and *Pleurophorus* sp. occur in a thin limestone 100 feet above the Weber quartzite. Norman D. Newell believes the specimens are related to elements in the Dinwoody formation of Wyoming (oral communication, 1942).

The writer found no infallible means of separating the Phosphoria and Dinwoody in Moffat County, and the contact remains where it was drawn by Sears (1925). Over 200 feet of unfossiliferous red beds separates the apparent top of the Phosphoria and the Shinarump conglomerate. These red beds thicken toward the west in Utah.

Southward from Glenwood Springs on the west side of the trough, erosion has removed the upper Paleozoic and apparently the Triassic as well, so that successively older beds are in contact with the Mesozoic. Near Crested Butte the Jurassic Entrada formation rests on Pennsylvanian red beds 2600 feet stratigraphically above the Mississippian. In the Monarch district Crawford (1913) reports erosion of 3000 feet of sediment from the section.

On the eastern side of the trough the highest stratigraphic unit present in the southern end of the Gore area is the Battle Mountain formation, probably of Des Moines age. In the Beaver-Tarryall area (Singewald, 1942) the Paleozoic red beds

are capped by "red shale of unknown age" overlain by the Morrison formation. In the Salt Creek area (Gould, 1935) farther south no post-Paleozoic beds have been reported.

PALEOGEOGRAPHY

Melton (1925), Lovering (1929), Johnson (1929), Ver Wiebe (1930), and Heaton (1933) have discussed the paleogeography of the Ancestral Rockies and have presented paleogeographic maps of the Pennsylvanian and Permian of Colorado.

Late Paleozoic rocks of west-central Colorado lie between the former Front Range landmass to the east and northeast and the Uncompahgre landmass to the west. These highlands, which have been positive areas since pre-Cambrian time (Lovering, 1929), were uplifted in early Des Moines time. The clay and soil which had accumulated on the highlands during late Mississippian subaerial weathering were washed into the surrounding seas and resulted in the deposition of the Belden shale. Lycopod plants and coal interbedded with marine limestone indicate that the surface of the trough stood very near sea level.

More rapid uplift of both highlands occurred in early Maroon time. Swift rivers built numerous deltas against both sides of the trough, while fine-grained sediment was carried into the center.

As the highlands rose the climate became drier. The flora became a dry-soil type. In lagoons and bays evaporation of sea water left beds and lenses of gypsum. In mid-trough the normal marine fauna disappeared. As the highlands continued to rise the sediments became brighter red. On the eastern side of the trough, in the Gore, McCoy, and Moffat County areas, marine faunas persisted later in Maroon time. A few fossils have been found relatively high in the section on the west side of the trough (Cement Creek and Sopris detailed sections). The western edge of the trough is covered or eroded off in many localities so that a direct counterpart of the Gore and McCoy areas is not available.

In late Des Moines or possibly in late Pennsylvanian time a flood of white sand from the north deposited the Weber quartzite. Much of this sand probably came from reworking of earlier Pennsylvanian sediments; however, there were undoubtedly local additions. By this time the highlands had been reduced in height, and State Bridge-Phosphoria time saw the deposition of red shale and siltstone from both highlands. A few conglomerate beds apparently had their source in the west as did the bulk of the State Bridge in the middle of the trough. This seems to indicate that the Uncompahgre highland stood higher than the Front Range during State Bridge time.

Triassic erosion removed a part of the Pennsylvanian and all the Permian sediments from the southern part of the region.

SUMMARY

The Belden shale is found in many localities in west-central Colorado. For this reason it is raised to formational rank. It probably grades into the lower McCoy formation. Its fauna is indicative of Des Moines age. The term Morgan formation is applied to the older Pennsylvanian sediments in Moffat County. Its fauna indicates that this formation may be correlated with the Des Moines also. The term

Maroon formation is applied to yellow and red beds overlying the Belden shale. The Maroon is equivalent to the upper McCoy, the Battle Mountain and the Morgan formations. Although the upper Maroon is without fossils it is probably all of Des Moines age. The gypsum in the Maroon formation is clearly Des Moines in age.

The term Weber quartzite is applied in its proper sense in west-central Colorado to a sandstone overlying the Maroon formation. The Weber is unfossiliferous here and may be upper Des Moines or upper Pennsylvanian.

The lateral range of the State Bridge formation is extended to the south where it includes several thousand feet of red beds formerly assigned to the Maroon. Diagnostic fossils are lacking, but it is believed to correlate with the Phosphoria of northwestern Colorado.

DETAILED SECTIONS

Yampa Section (no. 1)

Measured in the valley of Disappointment Creek, Moffat County, Colorado, secs. 1 and 2, T. 5 N., R. 100 W. and sec. 31, T. 6 N., R. 99 W.

Top of section Interval	Feet
"Shinarump conglomerate" (Triassic) Phosphoria formation or Dinwoody formation (?) 43. Shale and siltstone interbedded, dark-red with gray bands, gypsiferous	218
Phosphoria formation (Permian) 42. Shale and sandstone olive green, weathers yellow, shale gypsiferous; sandstone fine-grained, thin-bedded. Fossils in limestone float fragments	114
Weber quartzite (Pennsylvanian) 41. Shale and sandstone light-gray, fine-grained, thin-bedded, lumps of petroliferous sand in shale	113
40. Sandstone white-gray,* weathers yellowish gray, fine-grained, cross-bedded, massive, gradational contact with interval 39	767
Morgan formation 39. Sandstone buff-yellow, buff beds weather burnt orange, fine-grained, thin-bedded, cross-bedded	118
38. Limestone buff, with brown chert, weathers with rough surface	6
37. Sandstone salmon pink-yellow, fine-grained, cross-bedded, fore-set beds dip generally S., NW., E.	45
36. Limestone gray, crystalline	2
35. Limestone buff, sandy	5
34. Sandstone pale lavender, thin-bedded, cross-bedded, fore-set beds dip generally S., SW. Thins to 10 feet of yellow sandstone 150 feet east	34
Small anticline, offset .5 mile east on interval 33 33. Limestone light gray with red chert, upper part argillaceous. Contains *Fusulinella* sp., *Archeocidaris* spines, *Dictyoclostus portlockianus*	10
32. Sandstone yellow, fine-grained. Thickens to 82 feet .5 mile NE. by intercalation of flesh-colored, extremely cross-bedded sandstone	26.5
31. Limestone light gray, brown-red chert, silicified *Composita* sp.	11
30. Sandstone white, fine-grained, irregularly bedded	8
29. Sandstone gray-brown, fine-grained, thin-bedded, cross-bedded, calcareous	58.4
28. Limestone light gray with red chert, partly covered. Contains *Dictyoclostus portlockianus*, *Chonetina* sp.	16.5
27. Sandstone lavender, fine-grained, thin-bedded, yellowish brown near top	37

* Hyphen used between colors or grain sizes means beds having both colors (or both sizes) are present in interval; if "to" replaces hyphen, color and size are intermediate (white to gray, e.g.).

	Feet
26. Limestone light gray: lower 2 feet sandy, fossiliferous; upper 8 feet crystalline, cherty	10
25. Sandstone salmon pink, fine-grained, massive, weathers thin-bedded, calcarerous	15
24. Limestone light gray, finely crystalline. Weathers buff	6.5
23. Sandstone buff to pink, fine-grained, thin-bedded, cross-bedded, fore-sets dip generally SE. and E.	21.6
22. Sandstone purple, fine-grained	5
21. Limestone light gray, crystalline. Contains crinoid columnals	3
20. Sandstone white, fine-grained. Contact gradational with interval 21	2
19. Sandstone pink, weathers burnt orange, fine-grained, massive, ledge former	27
18. Sandstone white, fine-grained	5
17. Limestone light gray, massive, traces of cross-bedding, red chert in lenses about 8 feet long.	10
16. Sandstone white, fine-grained, quartzitic	2
15. Covered	14
14. Sandstone pink, weathers burnt orange fine-grained, ledge former	6
Section ends .5 mile west of Spurgin Ranch. Offset on interval 14 1 mile north of ranch.	
13. Limestone light gray, very coarsely crystalline. Contains *Orthotichia schuchertensis*, *Spirifer rockymontanus*	4
12. Covered	25
11. Sandstone flesh-colored, fine-grained, ledge former	5
10. Limestone light gray, coarsely granular, fossiliferous	3
9. Sandstone flesh-colored, fine-grained, cross-bedded, fore-sets dip generally S. and SW., soft, ledge former	21.6
8. Sandstone burnt orange, pink near top, fine-grained, lumps of gray limestone, ledge former	27
7. Sandstone white, fine-grained, thin-bedded	5
6. Covered	16
5. Sandstone white, fine-grained, quartzitic	4
4. Limestone and shale; limestone light gray, crystalline, with red and purple chert, ledges 2 feet thick; shale light gray, partly covered with some thin, white sandstone in covered portion	65
3. Covered	54
2. Limestone light gray, crystalline, with much red chert, contains bryozoans	32.4
1. Limestone light gray, crystalline, red chert in ledges. Partly covered with ledges appearing	194.4
Section begins 12 miles west of Elk Springs, near junction of Mandel Ranch road with county road.	
Mississippian limestone	
Total	2127.9

Miller Creek Section (no. 3)

Top of section Interval	Feet
"Shinarump conglomerate?"	
State Bridge formation	
72. Shale and sandstone interbedded, reddish-brown, slightly calcareous	67
71. Limestone brown, weathers purplish-gray. Weathered surface looks like "Swiss cheese".	.3
70. Sandstone light brown, fine-grained, almost a siltstone, irregular bedding	42.4
69. Sandstone olive-green, fine-grained, irregular bedding, some thin shale beds	26
68. Covered	22
67. Sandstone dark gray, weathers light gray, fine-grained, calcareous	5.5
66. Covered	40
65. Shale and sandstone in alternating beds, yellow; sandstone fine-grained	120
64. Shale brownish-red, micaceous, irregular bedding	5
63. Shale yellow, dark gray near top of interval; a few thin beds of yellow sandstone	16
62. Sandstone gray, weathers tan, cross-bedded, fore-sets dip generally N. and W., fine-grained	7.8
61. Sandstone yellow, patches of gray, weathers into irregular thin beds; ripple-marked, cross-bedded, fore-sets dip generally N. and NE	65
60. Covered. Float indicates some red siltstone and shale	147

	Ft.
Section ends on W. side of Miller Creek at mouth. Offset to crest of small anticline 1000 feet NE. of Miller Creek Bridge over White River.	
59. Dolomite breccia gray, weathers buff, perhaps algal	2
58. Sandstone lavender with gray spots, fine-grained, slightly calcareous	4
57. Siltstone dark red, streaks of gray, muddy, irregular bedding, slightly calcareous	78
Weber quartzite	
56. Sandstone grayish-tan, weathers tan, fine-grained, quartzitic, cross-bedded, ledge former. Sandstone becomes yellower and softer near top of interval	70
Maroon formation	
55. Sandstone reddish-brown with green streaks, fine-medium-grained, micaceous, soft	6.4
Section ends on west side of Miller Creek at mouth. Offset to canyon just northwest of school house on N. side of White River.	
54. Covered	220
53. Sandstone like interval 51	110
52. Sandstone purple, medium-grained, soft	6
51. Sandstone tannish-red, medium-grained, ledge former	22.5
50. Sandstone red, medium-grained, thin-bedded	7
49. Sandstone purplish-gray, very limy, almost a limestone, fine-grained	2
48. Sandstone reddish-tan, fine-medium-grained, thin-bedded	20
47. Sandstone, purple, medium-grained, micaceous	2
46. Sandstone and shale interbedded, brownish-red; sandstone fine-grained, micaceous	50
45. Limestone medium gray with purple bands, crystalline	.8
44. Sandstone brownish-red, fine-medium-grained, shale breaks	30
43. Sandstone tan-peach colored, fine-grained, calcareous	25
42. Sandstone red-tannish red, medium-grained	100
41. Limestone medium gray, crystalline, with thin layers of purple sandstone	8
40. Sandstone red-dark red, fine-medium-grained, micaceous, calcareous	33
39. Sandstone and shale interbedded, red; sandstone fine-grained, thin-bedded; shale micaceous	100
38. Sandstone reddish-tan, fine-grained, thin-bedded	54
37. Sandstone and shale interbedded, purple; sandstone medium-grained; shale micaceous	4
36. Similar to interval 35 but contains beds of red, micaceous shale	21
35. Sandstone red occasional gray streaks, fine-medium-grained	75
34. Sandstone purplish-gray, fine-grained	5
Small anticline	
33. Sandstone red, medium-fine-grained, micaceous, calcareous	53
Section ends on S. side of Moog Gulch. Offset on interval 26 to N. side of Gulch	
32. Sandstone white, fine-grained, contact with interval 31 gradational	1
31. Sandstone red, fine-medium-grained, micaceous	103
30. Covered probably red sandstone	14.1
29. Sandstone, light gray, fine-grained	14
28. Limestone, light gray, finely crystalline	.8
27. Sandstone pinkish-red, medium-grained	4
26. Limestone medium gray, crystalline	4
25. Sandstone pinkish-red, fine-medium-grained	13
24. Covered; probably yellow or red sandstone	22
23. Sandstone yellow, fine-grained, thin-bedded	14.2
22. Sandstone red, fine-medium-grained	55
21. Sandstone light greenish gray-white, fine-grained, micaceous, calcareous	19
20. Limestone light gray, crystalline, small rounded grains of quartz	1
19. Sandstone similar to interval 18, but color is brownish-red	45
18. Sandstone reddish-brown with gray streaks, fine-grained, micaceous, calcareous	37.6
17. Covered probably brown sandstone	51.7
16. Limestone dark gray, crystalline	1
15. Covered	23.5
14. Limestone dark gray, weathers rotten like gypsum caprock	3
Axis of small anticline	
13. Limestone and shale; limestone blue gray, finely crystalline	8
12. Sandstone light gray, weathers yellow, fine-grained, calcareous, contains gypsum along strike	67

Section begins on W. side of Miller Creek .5 mile N. of the mouth of the West Fork of Miller Creek. Offset on interval 11 from the top of cliff on north side of trail to Widow Spring just above Miller Creek.

	Feet
11. Limestone light gray, finely crystalline. Contains *Marginifera muricatina, Dictyoclostus portlockianus, Composita subtilita*	27
10. Sandstone similar to interval 8, fossiliferous	4
9. Limestone dark gray, crystalline	5
8. Sandstone light gray, fine-grained, calcareous	6
7. Limestone dark gray, crystalline, some layers look like an edgewise breccia. Turns to breccia toward the north; fossiliferous	27
6. Sandstone yellowish-buff-gray, some beds weather reddish-brown; fine-grained, calcareous; thin yellow shale breaks	187
5. Covered	5
4. Sandstone black with white flecks of calcite, granular, calcareous. Some gypsum north along strike	1
3. Sandstone buff, weathers tan; fine-grained, calcareous	35
2. Covered	16
1. Sandstone buff, fine-grained, calcareous	26

Begin section on N. side of Widow Spring trail, just S. of the confluence of the Middle Fork and East Fork of Miller Creek.

Total	2562.7

Glenwood Springs Section (no. 5)

Section measured in the vicinity of Glenwood Springs, Colorado, ends on the E. side of the first stream valley E. of South Canyon Creek, 4 miles W. of Glenwood Springs.

Top of section

Interval	Feet
Shinarump conglomerate	
Dinwoody formation (Moenkopi formation)	
71. Shale red, fissle	25
70. Limestone dark gray to white, algal, contact gradational with interval 69. Contains *Anodontophora* sp. and *Pleurophorus* sp.	3
69. Mudstone olive greenish-gray, purple near top, indistinct bedding	100
Weber quartzite	
68. Sandstone white streaks of gray, calcareous, fine-grained, petroliferous	79
Maroon formation	
67. Grit pinkish-gray, streaked with red	18
66. Sandstone and shale dark red; shale micaceous	36
65. Sandstone and conglomerate pink at base, grayish-white above, rounded pebbles of quartz, schist, and granite up to 6-inch diameter; calcareous, cross-bedded, ledge former	10
64. Sandstone and siltstone red; sandstone fine-grained, some beds slabby, others massive, cross-bedded	126
63. Sandstone brick-red to pinkish-red, with a few gray streaks, medium-grained; conglomeratic with subangular pebbles of quartz and acid igneous rocks	25
62. Sandstone fine-grained, and siltstone and shale, micaceous, calcareous	111
61. Sandstone red, medium-grained, calcareous	7
60. Covered, probably brick-red siltstone and fine-grained sandstone	69
59. Sandstone red, medium-coarse-grained	14
58. Siltstone and sandstone; siltstone brick red; sandstone red, fine-grained, slabby	85
57. Sandstone pinkish-red, medium-grained, strongly cross-bedded, calcareous	8
56. Sandstone and siltstone bright red, micaceous, cross-bedded; sandstone fine-grained	42
55. Sandstone and conglomerate bright red, grayish at top; conglomerate contains pebbles of quartz and potash feldspar	20
54. Covered, probably some brick-red siltstone	29
53. Sandstone bright red, coarse-grained, conglomeratic	42
52. Siltstone brick red, partly covered	21
51. Sandstone pinkish-light red, coarse- to medium-grained; coarse-grained beds conglomeratic, arkosic	42

	Feet
50. Siltstone and shale brick red, micaceous	5
49. Sandstone brick red, medium-grained, arkosic	22
48. Siltstone brick red, micaceous	27
47. Sandstone pinkish-red, coarse-grained, conglomeratic, subangular pebbles of quartz up to 1-inch diameter, arkosic	36
46. Siltstone brick red, micaceous, upper part massive; lower thin-bedded	36
45. Sandstone pinkish-red, coarse-grained, conglomeratic, subangular pebbles of quartz up to 1-inch diameter, thins rapidly to N. This is the lowest of the bright-red beds to be noticeably calcareous	45
44. Siltstone and fine-grained sandstone, brick red, micaceous	61
43. Sandstone pinkish-red, coarse-grained, arkosic. Composed of two prominent beds separated by a soft layer of medium-coarse-grained sandstone	100
42. Partly covered. Alternating beds of siltstone and fine-grained sandstone, brick red, some coarse-grained, red, sandstone, cross-bedded	520
41. Sandstone pinkish-red-bright red, medium-coarse-grained, arkosic, massive, cross-bedded.	18
40. Sandstone and shale brick red, some beds of siltstone; sandstone fine-grained to medium-grained, arkosic	121
End section on hillside behind ranch on S. side of Colorado River. Offset .5 mile W. to locked gate on abandoned R.R. right of way.	
39. Sandstone brick red, fine-grained, partly covered	40
38. Sandstone pinkish-bright red, coarse-grained, arkosic, conglomeratic, pebbles quartz ¾-inch in diameter	10
37. Sandstone brick red-bright red, fine-grained, some beds of siltstone of the same color	70
36. Siltstone brick-red, massive	12
35. Sandstone pinkish-bright red, coarse-grained, arkosic	10
34. Siltstone brick red, thin-bedded, micaceous	48
33. Sandstone pinkish-red, coarse-grained, arkosic, conglomeratic pebbles rounded to subangular quartz and pink feldspar	8
32. Sandstone dark red-brick red, fine-grained, thin-bedded, micaceous	144
Base of the bright red sediment. Offset to S. side of Colorado River, behind ranch house.	
31. Sandstone and shale, dark red, .5 feet of gray limestone 40 feet below top of interval	112
30. Limestone gray, weathers brownish gray, arenaceous	3
29. Sandstone dark red to reddish-tan, fine- to medium-grained, arkosic, thin-bedded, partly covered	225
28. Limestone yellowish-gray, weathers buff, arenaceous, contains a pinkish-tan, medium-grained sandstone	2
27. Sandstone and shale gradually changes from tan to brown to dark red going up in the interval, fine- to medium-grained, micaceous, arkosic, calcareous	848
26. Sandstone and shale similar to interval 24	78
25. Limestone gray, weathers brownish gray, lumpy bedding, looks like dolomite	2
24. Sandstone and shale interbedded; sandstone brownish-gray; shale gray, micaceous, calcareous	215
23. Limestone gray, weathers yellow, rotten	2
22. Sandstone gray and grayish-brown, partly covered, fine- to medium-grained, thick- to thin-bedded, calcareous	141.5
21. Covered probably gray sandstone and shale	150
Section ends on mountainside just E. of Glenwood Springs. Offset to W. side of Mitchell Creek .3 mile S. of State Fish Hatchery. Section begins at road level.	
20. Limestone breccia, matrix yellow, fragments gray, caps gypsum locally	1
19. Gypsum white	80
Belden shale	
18. Limestone and shale interbedded; shale black, fissle; limestone dark gray, thin-bedded, muddy, dark-red band at top	297
17. Limestone dark gray, muddy, light calcite stringers	3
16. Shale and limestone interbedded; shale gray, laminated limestone dark gray to light gray, thin-bedded, muddy	35
15. Limestone with thin shale breaks, dark gray, thin-bedded	25
14. Limestone light gray, mottled surface. Contains crinoid and echinoid fragments, fenestellid bryozoans, *Paeckelmannia* n. sp., *Marginifera muricatina*, *Spirifer rockymontanus*, *Neospirifer* sp.	2
13. Shale gray, laminated	3
12. Limestone light gray, muddy, blocky fracture	1
11. Covered probably shale and limestone	46

	Feet
10. Limestone dark gray, layers of black chert, irregular fracture	2
9. Covered probably gray limestone and shale	92
8. Limestone light gray	.5
7. Covered	25
6. Limestone and chert; limestone gray, weathers yellow, contains beds and nodules of black chert	2.5
5. Covered; probably gray limestone and shale	61
4. Limestone dark gray, weathers buff, muddy	1.5
3. Limestone and shale interbedded, gray; limestone muddy	.5
2. Limestone dark gray, weathers buff	1.5
1. Shale and limestone interbedded, gray; limestone muddy	5

Regolith dark red 1–2 feet thick

Leadville limestone

Section begins 250 feet E. of pipeline on S. bank of Colorado River at Glenwood Springs.

Total of Pennsylvanian sediments 4501

Sopris Section (no. 6)

An incomplete section measured in the valley of Crystal River between Avalanche Creek and Bill's Creek. Section ends on the north side of Bill's Creek 8 miles south of Carbondale, Colorado.

Top of section

Interval	Feet
Chinle formation	
Maroon formation	
145. Sandstone dark red, fine-grained, micaceous, calcareous, contains nodular limestone streaks	43
144. Siltstone light brick red-peach-colored, thick to thin-bedded	15
143. Sandstone fine-grained, micaceous, cross-bedded, fore-sets dip generally N., W., SE.	13
142. Siltstone similar to interval 144	13
141. Sandstone purplish-red, fine-grained	9
140. Siltstone light brick red to peach-colored, thin-bedded, micaceous	17.2
139. Sandstone purplish-red, fine-grained, micaceous	36
138. Siltstone peach-colored, some layers thin-bedded, calcareous	31
137. Sandstone red with gray streaks, fine-grained, micaceous, a few lenses of nodular, gray limestone	47.3
136. Sandstone pinkish-purple, fine-medium-grained, arkosic, conglomeratic, pebbles of acid igneous and metamorphic rocks 3-inch diameter, cross-bedded, much lumpy bedding	51.6
135. Sandstone pinkish-red, fine-grained, micaceous	43
134. Sandstone purplish-pink with gray streaks, medium-coarse-grained, arkosic, conglomeratic in streaks, pebbles of acid igneous and metamorphic rocks 5-inch diameter	36.7
133. Siltstone brick red, with some beds of fine-grained, purplish-red, sandstone	51.7
132. Sandstone pinkish-red, medium-coarse-grained, conglomeratic, pebbles igneous and metamorphic rocks 10-inch diameter	32.9
131. Siltstone brick-red, thin-bedded	18
130. Sandstone similar to interval 132, but pebbles 3-inch diameter	32.9
129. Sandstone dark red, fine-grained, micaceous, filled with small, calcareous nodules	14
128. Sandstone purplish-red, fine-grained, conglomeratic, pebbles subangular-rounded, acid igneous and metamorphic rocks and quartz 3-inch diameter, lumps of light-gray limestone near top of interval	37.6
127. Siltstone brick red	30
126. Limestone purplish-gray, muddy, perhaps algal	2
125. Sandstone purplish-red, fine-grained at base, coarser above, conglomeratic, pebbles rounded, igneous and metamorphic rocks 3-inch diameter	18.8
124. Siltstone brick-red, thin-bedded, fine-grained	42.3
123. Sandstone purplish-red with gray streaks, fine-grained, a few thin pebble beds	4
122. Sandstone pinkish-gray, fine-grained, micaceous, grades upward into muddy siltstone	9.5
121. Limestone light gray, nodular, gritty	1
120. Sandstone pinkish-red, fine-grained	4.7
119. Limestone light gray, extremely gritty and lenticular	.8
118. Sandstone pinkish-red with gray streaks near base, brick red above, fine-grained	18.8

	Feet
117. Limestone brownish-purple, nodular, in brick red mudstone, thin, pure, gray limestone on top of interval	2
116. Sandstone dark red, fine-grained	7
115. Sandstone purplish-red, medium-grained, conglomeratic, contact gradational with interval 114	14
114. Sandstone and siltstone; sandstone red, fine-grained; siltstone brick red	47
113. Sandstone similar to interval 111	18.8
112. Sandstone red, fine-medium-grained	61
111. Sandstone pinkish-red, coarse-grained, strongly conglomeratic, pebbles subangular-rounded acid igneous and metamorphic rocks and quartz, 5-inch diameter, ledge former	15
110. Partly covered, some red sandstone	37
109. Sandstone pinkish-red, coarse-grained, conglomeratic near base, pebbles acid igneous rocks and quartz 5-inch diameter, arkosic	31
108. Siltsone red, cross-bedded	37.6

Section begins in the bottom of Bill's Creek valley. Offset from cliff on S. side of creek.

107. Sandstone red-pinkish-red, coarse-grained at top and bottom, 10 feet of massive conglomeratic sandstone in center	67.5
106. Siltstone and sandstone; siltstone brick red; sandstone fine-grained, thin-bedded	13
105. Sandstone red, coarse-grained, arkosic, conglomeratic, pebbles rounded quartz	31.5
104. Siltstone brick-red at base; grades up into purplish-red, medium-grained sandstone	76
103. Sandstone pinkish-red, coarse-grained, arkosic, occasional pebbles of acid igneous rocks	18
102. Sandstone purplish-red, medium-grained	18
101. Siltstone brick red, thin-bedded	18
100. Sandstone pinkish-red, medium-grained, beds of conglomerate with pebbles 3-inch diameter, cross-bedded	18
99. Similar to interval 97	37.6
98. Similar to interval 96	15
97. Sandstone and siltstone; sandstone red, fine-grained; siltstone brick red	55
96. Sandstone pinkish-red, coarse-grained, arkosic, scattered pebbles of quartz and feldspar 1-inch diameter	20
95. Siltstone and sandstone red; sandstone fine-grained	33
94. Sandstone red with gray streaks, medium-grained, contains pockets and streaks of pebbles 3-inch diameter	20
93. Sandstone pinkish-red, coarse-grained, conglomeratic, pebbles quartz, acid igneous and metamorphic rocks, rounded-subangular, 2-inch diameter, cross-bedded, cliff former	40
92. Siltstone and sandstone red; sandstone fine-grained, irregular bedding	30
91. Sandstone red with gray streaks, coarse-grained, occasional pebbles 2-inch diameter, ledge former	10
90. Sandstone red, fine-medium-grained	104
89. Sandstone pinkish-red, coarse-grained, conglomeratic, small pebbles of quartz, cross-bedded	10
88. Sandstone red, fine-medium-grained, weathers thin-bedded; cross-bedded	78.2
87. Sandstone red with gray streaks, coarse-grained, occasional pebble beds	27.3
86. Sandstone red to dark-red, medium-grained, cross-bedded	69
85. Sandstone purplish-red, coarse-grained, conglomeratic, pebbles similar to those in interval 84, arkosic	28
84. Sandstone pinkish-red, coarse-grained, conglomeratic, pebbles rounded-subangular, limestone, acid igneous and metamorphic rocks 5-inch diameter	14
83. Sandstone red with gray streaks, medium-grained, occasional pebbles	47
82. Conglomerate pinkish-gray, pebbles rounded-subangular, quartz, limestone, acid igneous and metamorphic rocks 5-inch diameter	14
81. Sandstone red, medium-fine-grained, micaceous	84.6
80. Conglomerate pinkish gray, pebbles limestone, acid igneous and metamorphic rocks 6-inch diameter, erosional contact with interval 79	12
79. Sandstone red, fine-medium-grained, thin-bedded	10

Offset ½ mile N. along cliff. To the N. interval 78 disappears as a conglomerate and interval 77 is 58 feet thick.

78. Conglomerate purplish-gray, pebbles rounded-subangular acid igneous, metamorphic rocks, green hornfels, rhyolite porphyry, light-gray limestone ½-inch diameter. Colonies of *Chaetetes milliporaceus*	8
77. Sandstone red with gray streaks, medium-grained, occasional pebbles, cross-bedded	48
76. Sandstone pink-pinkish gray, conglomeratic, pebbles light-gray, limestone, acid igneous and metamorphic rock, subangular-rounded, 3-inch diameter	5
75. Sandstone red-pinkish-gray, fine-coarse-grained, thin-bedded-massive, micaceous	22

	Feet
74. Conglomerate pinkish-gray, pebbles of quartz, feldspar, acid igneous rock, 1.5-inch diameter; calcareous	3
73. Sandstone red, medium-grained, massive, weathers thin-bedded, cross-bedded	153.4
72. Sandstone red, fine-grained, thin-bedded, occasional streaks of pebbles	150
71. Conglomerate pinkish-gray, pebbles of quartz, limestone, 5-inch diameter	9
70. Largely covered, some red sandstone	33.6
69. Sandstone red, fine-grained, thin-bedded	21
68. Sandstone pinkish-red with gray streaks, medium-coarse grained, occasional pebble beds, 8 feet of fine-grained sandstone near center of interval	54.6
67. Mudstone red, micaceous, very irregular bedding	9
66. Sandstone red, fine-grained, thick-thin-bedded	25.2
65. Conglomerate pink at base, gray above, pebbles rounded-subangular quartz, limestone, acid igneous and metamorphic rocks 9-inch diameter, some pebbles rotten, ledge former	29.4
64. Sandstone pinkish-red, medium-coarse-grained	8.4
63. Sandstone red, fine-grained, thin-bedded, micaceous	29.4
62. Sandstone red with gray streaks, fine-coarse-grained, streaks of small pebbles, some layers calcareous	13.6
61. Sandstone pinkish-gray, coarse-grained, conglomeratic, pebbles quartz, light-gray limestone, acid igneous and metamorphic rocks, 4-inch diameter	8.4
60. Sandstone pinkish-red, coarse-medium-grained, thick- to thin-bedded	29.4
59. Sandstone pinkish-red with gray streaks, medium-coarse-grained, occasional streaks of pebbles of quartz and acid igneous rocks, lumps of light-gray limestone around which red color is bleached to gray, cross-bedded	12.9
58. Sandstone red, fine-grained, thin-bedded, micaceous	12.6
57. Sandstone pinkish-red with gray streaks, coarse-grained, conglomeratic, pebbles subangular quartz, feldspar, light-gray limestone, 4-inch diameter	25.2
56. Partly covered, sandstone pinkish-red, medium-grained	105
55. Sandstone pinkish-red, coarse-grained, conglomeratic, pebbles light-gray limestone, acid igneous and metamorphic rock, rounded to subangular, 6-inch diameter, weather easily	16.8
54. Sandstone red, fine-grained, micaceous	12.6
53. Covered, some fine-grained red sandstone	92
52. Sandstone red, medium-grained, some layers thin-bedded	71.4
51. Sandstone pinkish-red, coarse-grained, occasional pebbles of igneous rock, partly covered	15.3
50. Sandstone red, fine-grained, thin-bedded, micaceous, calcareous, contact gradational with interval 49	10.2
49. Sandstone pinkish-red, coarse-grained, conglomeratic, pebbles subangular quartz, gray limestone, acid igneous rock 3-inch diameter, calcareous, cross-bedded	15.3
48. Sandstone red, medium-grained, massive-thin-bedded, some layers cross-bedded	56.5
47. Sandstone pinkish-red with gray streaks, conglomeratic, pebbles subangular quartz, feldspar, limestone, 4-inch diameter, strongly calcareous, massive	40.8
46. Sandstone red, fine-grained, thin-bedded, micaceous, calcareous	7.6
45. Sandstone purplish-red, coarse-medium-grained, cross-bedded, noncalcareous	10.2

Begin section at level of old road above irrigated land on N. side of Nettle Creek. Offset from top of hill on S. side of Nettle Creek.

44. Sandstone pink, coarse-grained, arkosic, conglomeratic, pebbles quartz, fossiliferous limestone, acid igneous and metamorphic rock, massive	29
43. Sandstone pinkish-red, medium-grained, cross-bedded, thin-to-thick-bedded, lumps of red shale near base, occasional streaks of pebbles 4-inch diameter	67
42. Shale dark red, fissile, micaceous, contains limestone nodules	1.5
41. Sandstone red, medium-fine-grained, thin-thick-bedded, cross-bedded	66
40. Sandstone pink, coarse-grained, conglomeratic, pebbles subangular quartz, acid igneous and metamorphic rock 3-inch diameter	13.6
39. Sandstone dark red, medium-grained, massive, weathers thin-bedded, streaks in lumps of gray limestone	23
38. Limestone brownish-purple-gray, nodular, in dark-red shale	2
37. Sandstone pinkish-red, coarse-grained, conglomeratic, pebbles subangular to rounded quartz, limestone, red shale, acid igneous and metamorphic rock	17
36. Limestone purplish-brown, nodular, in dark-red and green shale, irregular bedding	2
35. Sandstone pinkish-red with gray streaks, medium-coarse-grained, arkosic, occasional subangular pebbles 2-inch diameter	72.8
34. Sandstone brick red, very fine-grained, micaceous	11
33. Sandstone pinkish-red, medium-coarse-grained, thick-thin-bedded, cross-bedded, occasional quartz pebbles .5-inch diameter	41.6
32. Siltstone brick red, thin-thick-bedded	10
31. Sandstone pinkish-red, medium-grained, cross-bedded, fore-sets dip N., SW., S.	52

	Feet
30. Sandstone pinkish-red, coarse-grained, conglomeratic, pebbles quartz, light-gray limestone, acid igneous and metamorphic rock 3-inch diameter	10.4
29. Sandstone pinkish-red, medium-coarse-grained, cross-bedded	31.2
28. Sandstone dark red, fine-grained, thin-bedded, micaceous	6
27. Conglomerate pink, arkosic, pebbles subangular quartz, gray limestone, acid igneous, metamorphic rock 4-inch diameter	22
26. Limestone brownish-purple, nodular, in red siltstone, irregular bedding	8
25. Sandstone pinkish-red with gray streaks, coarse-grained, calcareous, occasional quartz pebbles	3

Section begins 1000 feet S. of Nettle Creek water tank at base of cliff. Offset from hill crest on S. side of Perham Creek. Probably some small discrepancy exists in this offset.

24. Similar to interval 23 colored darker red	25
23. Sandstone pinkish-gray, fine-coarse-grained, arkosic, micaceous, occasional pebbles of gray limestone, igneous and metamorphic rock	459
22. Partly covered, ledges of gray sandstone	90
21. Sandstone purplish-red-brownish-red, mainly fine-grained, micaceous, thin shale breaks, occasional feldspar pebbles	90

Base of the bright-red sediment.

20. Sandstone brown-gray, fine-coarse-grained; fine-grained portion micaceous, coarse-grained portion arkosic, conglomeratic, thin micaceous shale breaks	50
19. Dolomite light gray, weathers brown, massive, ledge former	30
18. Limestone and shale interbedded; limestone gray, thin-bedded, muddy, some oölitic limestone toward the north; shale dark gray-black	44
17. Sandstone brown, fine-medium-grained, thin-thick-bedded	214
16. Limestone gray, weathers brown, thin-bedded, finely crystalline, massive beneath, reeflike above	25
15. Sandstone gray, weathers brown, fine-medium-grained, thin-bedded, medium-grained layers thicker	162
14. Breccia brown, fragments of gray sandstone, weathers brown, 2 feet diameter, matrix calcareous, thickness variable	15
13. Limestone gray-brown, thin shale breaks, blocky fracture, finely crystalline, ledge former	15
12. Sandstone reddish-brown-gray, fine-medium-grained, occasional beds of conglomerate, thin shale breaks	65
11. Conglomerate light brown, arkosic, pebbles rounded-subangular limestone, dolomite, quartz, potash feldspar, gypsum 4-inch diameter, slightly calcareous	25
10. Sandstone gray, weathers brown, thin-bedded, fine-grained, calcareous	61
9. Limestone and shale interbedded; limestone dark gray; shale light gray, thin-bedded	2
8. Sandstone and shale interbedded; sandstone tan, conglomeratic, quartzitic, medium-grained; shale gray, micaceous	15.3
7. Shale and dolomite interbedded; shale gray; dolomite gray, weathers brown	6
6. Limestone dark gray, nodular, in gray micaceous shale	3
5. Sandstone gray, weathers brown, fine-grained, thin-bedded, calcareous, interbedded with thin gray shale	46
4. Covered	10
3. Sandstone yellowish-brown, fine-grained, thin-bedded	5
2. Dolomite gray, weathers brown, interbedded with limy gray and black shale	10.2
1. Covered, probably gypsum	150

Section begins on hillside west of Crystal River .5 mile N. of mouth of Avalanche Creek.

Total	5240.8

Eiby Creek Section (no. 10)

Section measured in valley of Eiby Creek N. of Eagle, Colorado. Section ends on plateau on W. side of Eiby Creek, about 4 miles N. of mouth.

Top of section

Interval	Feet
Shinarump conglomerate	
State Bridge formation	
84. Siltstone brick red to pinkish-buff, lenses of buff and purple siltstone	198
83. Sandstone gray, fine-grained, micaceous, calcareous	.5

	Feet
82. Siltstone and shale brick red	317
81. Limestone light gray-white, pink chert, some beds of breccia, arenaceous, algal	10
80. Siltstone brick red	140
79. Sandstone yellow, fine-grained, noncalcareous	90
78. Sandstone purplish-red, medium-grained, arkosic	5
Weber quartzite(?)	
77. Sandstone grayish-white, medium-grained, slightly calcareous, grades up into interval 78	46
Maroon formation	
76. Sandstone purplish-red, medium-grained, arkosic	31
75. Sandstone yellow, fine-grained, micaceous, thin-bedded, slightly calcareous, dark gray shale at base	10
74. Siltstone and sandstone interbedded; siltstone brick red, cross-bedded; sandstone purplish-red, medium-grained, arkosic	270
73. Limestone light purplish-gray, muddy	.2
72. Sandstone brick red, medium-grained, arkosic	104
71. Sandstone purplish-red, siltstone brick red, cross-bedded, most of sandstone in lower 125 feet	260
70. Limestone light gray, finely crystalline	.5
69. Sandstone and siltstone interbedded bright red; sandstone has beadlike lines of rounded grains of quartz	106
68. Limestone light gray, nodular	.2
67. Sandstone purplish-red, micaceous, slightly calcareous	20
66. Siltstone bright red, thin-bedded, calcareous	55
65. Sandstone bright red to purplish-red, medium-grained, arkosic, cross-bedded, some massive beds	156
64. Siltstone and shale bright red, many thick beds	41.5
63. Limestone light gray, crystalline	1.5
62. Sandstone and shale interbedded bright red; sandstone fine-grained, calcareous; shale laminated	67
Offset to west side of Eiby Creek on interval 61.	
61. Limestone light gray, finely crystalline. Rests on thin purple shale	2
Base of the bright-red sediment.	
60. Sandstone dark red, micaceous, thin-bedded, partly covered	32
59. Limestone dark gray, weathers brownish-gray, muddy	3
58. Covered, probably shale	4
57. Limestone light gray, muddy	2
56. Sandstone reddish-brown, fine-grained, partly covered	50
55. Limestone dark gray, finely crystalline	1
54. Sandstone and shale interbedded reddish-brown; sandstone fine-grained, micaceous; shale soft, mainly covered	49
53. Limestone light gray, finely crystalline, small nodules of black chert	4
52. Sandstone gray, fine-grained	15
51. Limestone dark gray, finely crystalline	2
50. Sandstone gray, micaceous, thin-bedded	15
49. Limestone light gray, crystalline, a series of thin beds	5
48. Sandstone brown, fine-grained	5
47. Limestone dark gray, finely crystalline	1
46. Sandstone brownish-red, medium-grained, arkosic	50
45. Limestone dark gray, banded, thin beds	1
44. Sandstone brownish-red, medium-grained, arkosic	6
43. Limestone dark gray, finely crystalline	1
42. Sandstone and shale interbedded reddish-brown to grayish-brown, fine-grained, thick- and thin-bedded, micaceous	45
41. Limestone dark gray, banded, algal	1.5
40. Sandstone and shale interbedded; shale gray; sandstone brown, fine-grained, micaceous	18
39. Shale dark gray, weathers grayish-green, laminated	20
38. Limestone and shale interbedded; limestone light gray, thin-bedded, muddy; shale gray	8
37. Sandstone and shale interbedded yellowish-brown-reddish-brown, micaceous; sandstone fine-grained	50
36. Limestone light gray, muddy	.5
35. Covered, probably shale	5
34. Limestone dark gray, muddy	1
33. Sandstone and shale interbedded yellowish-gray with beds of brown; sandstone fine-grained, thin-bedded, micaceous	55

	Feet
32. Limestone dark gray, thin-bedded	1
31. Sandstone brown, fine-grained, soft	15
30. Limestone light gray, thin-bedded, muddy	1
29. Sandstone and shale interbedded yellowish-brown, thin-bedded; sandstone fine-grained	35
28. Limestone light gray, thin-bedded, muddy	.5
27. Covered, some sandstone yellowish-gray, thin-bedded	10
26. Limestone light gray, thin-bedded, muddy	.5
25. Covered, probably gray sandstone and shale	20
24. Sandstone yellow, weathers yellowish-brown, fine-grained, cross-bedded, massive layer	15
23. Shale and sandstone interbedded; shale gray, weathers yellow; sandstone yellowish-gray, fine-grained, bedding planes have "cake frosting" marks	85
22. Limestone light gray, muddy, gray shale on top and bottom	1
21. Sandstone and shale yellowish-gray; sandstone fine-grained, thin-bedded, micaceous	105
20. Limestone light gray, muddy	1
19. Covered, probably yellowish-gray shale	15
18. Limestone dark gray, muddy	1
17. Sandstone and shale interbedded yellowish-gray, partly covered	82
16. Sandstone and shale interbedded reddish-brown; sandstone fine-grained, thin-bedded; shale soft	30
15. Limestone dark gray, banded	1
14. Covered	12
13. Limestone dark gray, wavy color bands	1
12. Sandstone with some shale; sandstone gray, weathers brown, ripple-marked, rather thick beds	91
11. Sandstone and shale interbedded yellowish-gray, weathers yellow, partly covered; sandstone fine-grained	85
10. Shale dark gray, fissile, calcareous	1
9. Shale and sandstone interbedded, yellowish-gray-yellowish-brown; shale arenaceous; sandstone fine-grained	18
8. Limestone dark gray, weathers buff, banded	1.5
7. Shale dark gray, arenaceous	15
6. Limestone and shale interbedded; three beds of limestone about 1 foot thick, dark gray, banded; shale dark gray, fissile with sandy lenses	7.5
5. Sandstone and shale yellowish-gray, partly covered	25
4. Sandstone and shaly sandstone reddish-brown, fine-grained	5
3. Shale and sandy shale yellowish-gray, micaceous	15
2. Limestone dark gray, banded	1
1. Covered, probably mostly yellowish-brown sandstone	21

Section begins 1000 feet upstream from gypsum plugs on E. side of Eiby Creek just N. of last ranch house (2 miles N. of Eagle).

Total	3099.4

Squaw Creek Section (No. 11)

Section measured on the N. side of the west fork of Squaw Creek, Eagle County, Colorado. Section ends near hillcrest on S. side of divide between west fork of Squaw Creek and Eagle River.

Top of section

Interval	Feet
Shinarump conglomerate	
State Bridge formation	
74. Siltstone tan, cross-bedded	24
73. Siltstone and shale interbedded, bright red, slightly calcareous, covered in middle of interval. 90 feet above base of interval internal and external molds of *Myalina* sp., *Pleurophorous* sp., and *Aviculopecten* sp. are present	320
72. Sandstone yellowish-white, fine-medium-grained, cross-bedded, arkosic	27
71. Siltstone bright red, thin-bedded	69
Maroon formation	
70. Sandstone purplish-red, medium-grained, arkosic	15
69. Siltstone bright red	20

	Feet
68. Sandstone and shale interbedded, bright red, micaceous; sandstone fine-grained	378
67. Limestone dark gray	2
66. Sandstone and shale dark red with gray streaks, partly covered, micaceous, slightly calcareous	376
65. Limestone light gray, crystalline	.7
64. Covered probably dark red sandstone	67
Base of bright-red sediment.	
63. Limestone light gray, some layers dark gray, stylolites	3
62. Sandstone and shale interbedded, partly covered, grades up from reddish-brown to red; sandstone fine-grained; shale laminated	200
61. Limestone light gray	1
60. Sandstone reddish-brown, fine-grained	30
59. Limestone light gray, almost lithographic, perhaps interbedded shale	10
58. Partly covered, some brown-reddish-brown sandstone and thin purple limestone	91
57. Limestone light gray, thin-bedded	.5
56. Covered; probably brown sandstone	25
55. Limestone light gray	1
54. Sandstone yellow, fine-grained, micaceous	6
53. Limestone light gray, wavy bedding	2.5
52. Sandstone brown, fine-grained, micaceous	60
51. Limestone dark gray, muddy	1
50. Covered; probably gray sandstone or shale	8
49. Limestone, gray, crystalline, with black chert nodules	1
48. Sandstone yellowish-brown, fine-grained, thin-bedded	58.5
47. Limestone dark gray, thin wavy bands of color	5
46. Sandstone yellow-gray, fine-grained, thin-bedded	45
45. Limestone dark gray, banded	4.5
44. Covered; probably gray sandstone	22
43. Limestone light gray, banded	1
42. Covered	8
41. Limestone dark gray, banded, with black chert	1
40. Sandstone yellowish-gray, fine-grained, micaceous	20
39. Limestone dark gray, banded	1
38. Sandstone brown, fine-grained	77
37. Limestone dark gray, finely crystalline with 1 foot of lighter-colored, thinner-bedded layers on top	10
36. Sandstone yellowish-gray, fine-grained	25
35. Limestone and limy gray shale; limestone light gray, thin-bedded	6
34. Sandstone yellowish-brown, thin-bedded, micaceous	66
33. Limestone gray, thin-bedded, banded	4
32. Sandstone and shale interbedded yellowish-brown; sandstone fine-grained	5
31. Limestone dark gray, weathers light gray	1
30. Sandstone brown and yellowish-brown, fine-grained	50
29. Limestone dark gray, banded	1
28. Sandstone and shale interbedded yellow, most of center of interval covered; sandstone fine-grained	245
27. Limestone and shale interbedded; limestone gray thin-bedded; shale gray, soft	5
26. Sandstone greenish-gray, fine-grained, micaceous	21
25. Limestone dove-gray, thin-bedded	.7
24. Covered; sandstone and shale	132
23. Limestone light gray, thin-bedded, muddy with paper shale	13.5
22. Shale and sandstone interbedded; shale gray, weathers yellow; sandstone yellowish-gray, fine-grained	22
21. Limestone similar to interval 17	10
20. Sandstone and shale interbedded, yellowish-gray, micaceous; sandstone fine-grained	22
19. Limestone similar to interval 17	1
18. Sandstone yellowish-gray, fine-grained	4.5
17. Limestone light gray, thin-bedded	1
16. Sandstone yellowish-gray, fine-grained, micaceous	13
15. Limestone black, thin-bedded, petroliferous, light gray near top	20
14. Sandstone yellow, fine-grained, micaceous	48
13. Shale dark gray, thin-bedded, very limy	2
12. Sandstone and shale interbedded, yellow-gray, micaceous	60
11. Limestone gray, thin-bedded, irregular beds	.6
10. Shale and sandstone yellow-gray, micaceous	33
9. Sandstone brown, fine-grained, ripple-marked	1

	Feet
8. Shale and sandstone interbedded, yellow; sandstone fine-grained, thin-bedded	69
7. Sandstone and shale interbedded yellow with brown bands, some shale gray, weathers yellow; sandstone fine-grained	212
6. Limestone gray, weathers brown, looks like dolomite	1
5. Shale and sandstone yellow, micaceous	86
4. Gypsum white, thickness varies	17
3. Limestone dark gray, thin-bedded at base; above light gray, weathers brown, looks like dolomite	13
2. Sandstone and shale interbedded gray; sandstone fine-grained shale laminated	54.5
1. Partly covered, upper part sandstone and shale greenish-gray, micaceous	133

Section begins at road level on west fork of Squaw Creek. SW. corner sec. 2, T. 5 S., R. 83 W.

Total 3390

Frying Pan Section (No. 14)

Section measured in the valley of Frying Pan Creek between Thomasville and Seven Castles Creek. Section ends in amphitheater 1.5 miles N. of Frying Pan Creek 3 miles E. of Basalt, Colorado.

Top of section

Interval	Feet
Shinarump conglomerate	
State Bridge formation	
52. Shale red, indistinct bedding, non-calcareous	109
51. Sandstone and shale interbedded; sandstone pinkish-gray, conglomeratic, pebbles of rounded quartz; shale red	109
50. Sandstone, shale and siltstone interbedded dark red; sandstone fine-grained	382
49. Sandstone yellowish-tan, fine-grained, cross-bedded, soft, noncalcareous	77
48. Sandstone dark red, fine-grained	10
47. Sandstone tan, fine-grained, soft, calcareous	5
46. Sandstone reddish-tan to reddish-brown, fine-grained, cross-bedded, micaceous, some medium-grained, conglomeratic beds which are noncalcareous, many ripple marks, cliff former	1200
Interval 46 forms cliffs on Seven Castles Creek. Offset from 1.5 miles W. of Sloss.	
45. Shale and sandstone dark red to brick red, micaceous, calcareous; sandstone thin-bedded, ripple-marked, some conglomerate beds with shale pebbles 2 inch diameter	722
44. Sandstone peach colored, fine-medium-grained, cross-bedded, noncalcareous	21
43. Shale red, arenaceous, not well laminated	35
42. Sandstone peach-colored, banded with darker lines, fine-medium-grained, cross-bedded, calcareous, ripple-marked	49
41. Mostly covered, contains reddish sediments at base, siltstone and fine-grained sandstone above	153
40. Limestone light gray, purple streaks, algal	1.5
39. Siltstone and sandstone interbedded, brick-brownish-red, thin-bedded, some portions massive, others shaly; sandstone fine-grained, micaceous, calcareous	30
38. Siltstone and shale interbedded, red	93
37. Sandstone pinkish-tan with darker bands which weather faster than lighter, fine-grained	478
36. Sandstone salmon colored-pinkish-tan, fine-medium-grained, very cross-bedded, slabby, noncalcareous except near top, faintly ripple-marked	873
35. Sandstone salmon-colored, fine-grained, noncalcareous, massive. At a distance interval appears redder than interval 36. Seems to be unconformity at top of interval	1277
34. Sandstone, shale and siltstone, brick red; sandstone fine-grained, noncalcareous; shale calcareous. Base of State Bridge formation probably lies somewhere in this interval	1137
Maroon formation.	
33. Covered	60
32. Breccia in limy red shale, incompetent bed	20
Fault on N. side of Frying Pan Creek opposite camp ground.	
Offset from S. side of creek.	
31. Sandstone, shale and siltstone brick red; sandstone fine-grained; shale laminated	170
30. Covered	100

	Feet
Much gypsum between intervals 29 and 30 in the vicinity of Ruedi.	
Offset from hills N.W. of Thomasville.	
29. Sandstone gray and reddish-brown, fine-grained, thin-bedded, micaceous. Much of this interval covered. Base of red sediment is somewhere near top	1100
28. Sandstone and dark limy shale; sandstone gray, contains *Walchia* sp. and *Calamites* sp.	4
27. Sandstone greenish-gray-brownish-red, fine-grained, micaceous, a few thin beds of gray crystalline limestone	473
26. Limestone yellow-buff, arenaceous	5
25. Covered	40
24. Limestone light gray, weathers bright yellow, spongy, arenaceous	8
23. Sandstone gray, weathers brown, fine-grained, micaceous, partly covered	278
22. Covered, much limestone similar to interval 21 in float	45
21. Limestone light gray, weathers yellowish-brown, spongy, looks dolomitic but is not	3
20. Covered; perhaps contains gypsum .5 mile W.	120
19. Limestone, light gray, much white calcite, crystalline	1
Belden shale.	
18. Sandstone and shale interbedded; sandstone gray, weathers brown, fine-grained, lumps of black shale in some beds; shale black, fissile	94
17. Covered; probably gray limestone and shale	161
16. Limestone dark gray with much white calcite	2
15. Covered; mostly limestone and shale in float	188
14. Limestone and shale interbedded gray, some thin limestone breccia	51
13. Limestone breccia, fragments light in darker matrix	9
12. Limestone and shale interbedded; limestone gray and muddy, shale dark gray	51
11. Limestone breccia dark gray, dark fragments 2 inch diameter in lighter matrix	1.5
10. Covered	5
9. Limestone breccia gray, dark fragments less than 1 inch diameter in lighter matrix	.5
8. Limestone and shale interbedded; limestone dark gray, muddy; shale black	5.5
7. Limestone light gray, muddy	1
6. Covered, Lime Creek road	28
5. Limestone light gray, muddy	2
4. Covered	11
3. Limestone gray, with pink calcite stringers	2
2. Shale and limestone interbedded gray, partly covered	37
1. Regolith dark red	1
Leadville limestone	
Section begins on knoll between Frying Pan and Lime Creeks just E. of Thomasville.	
Total	9839

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University of Chattanooga, Chattanooga, Tennessee.

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